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BIOELECTROMAGNETIC EFFECTS OF EMP: PRELIMINARY FINDINGS

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EXECUTIVE SUMMARY

Facilities to simulate electromagnetic pulses (EMPs) are used to test military equipment and electrical communications devices for resistance to the effects of an EMP caused by an upper-atmospheric nuclear detonation. The rapid rise time and high field strengths (0.1-50 kV/m) of an EMP distinguish it from other electromagnetic phenomena. Certain types of EMP simulators also expose facility operators and members of the public to electromagnetic fields of varying intensity as do other natural sources such as the fields produced near a lightning bolt.

Limited biological effects data have been collected to assess the potential EMP health hazards to humans. Evidence from the available database does not establish that EMPs represent either an occupational or a public health hazard. A critique is presented of the EMP research published to date in order to explore its limitations and similarities with related outcome experience from other electromagnetic field research. Laboratory research and multiple years of observations on workers in existing EMP manufacturing and simulation facilities suggest that there are no acute or short-term health effects. The occupational exposure guideline for EMP is 100 kV/m, which is far in excess of usual exposures with EMP simulators.

There are many persistent questions surrounding biological effects of electromagnetic fields. Based on these concerns, research needs are identified for determining to what extent biological systems exposed to EMPs reflect phenomena currently being observed with other electromagnetic exposure regimens. Additional options relate to continuing medical surveillance of occupationally exposed personnel and studies of communities proximal to EMP simulators.

1. INTRODUCTION

Electromagnetic pulses (EMPs) are a national defense concern. Both military operations and civilian facilities potentially could be incapacitated by a strategic EMP (Yapoujian 1986; EPRI 1987). Accordingly, the U.S. armed forces are conducting simulations of EMP to identify vulnerable military devices and to validate "hardening" efforts. Effects of these simulated EMPs are more localized than those that may be produced by an atmospheric nuclear detonation. For this reason the populations of greatest concern for potential health risks are the personnel operating the simulators and other persons (possibly members of the public) within immediate proximity of the test facility.

An EMP produces far less total electromagnetic energy than lightning, yet has a much more rapid rise time. It is the rapidity of EMP, not the intensity alone, that poses an impact to unprotected electrical equipment. In fact, electrical fields monitored under storm clouds (10 kV/m) may be tenfold to 100-fold greater in intensity than public exposures from EMP simulators (LBERI 1977). There is a consensus in the published literature among manufacturers of EMP simulators, and by the Occupational Safety and Health Administration, that electromagnetic fields produced by EMP simulators are innocuous (Meyerson and Morgan 1987). Despite this mutual agreement, there is persistent public apprehension about general health risks posed by electromagnetic fields. Much of this anxiety currently arises from health effects alleged to be associated with electromagnetic exposures that are vastly different from those associated with EMP

simulators, e.g., power distribution frequencies (60 Hz). Many of the early 60-Hz studies were similar in design and scope of investigation to those which have been conducted thus far with EMP. Only recently have a variety of biological measures sensitive to electromagnetic fields been identified for 60-Hz studies.

This document will describe and discuss available biologic data derived from experiments specifically utilizing EMP simulations to provide exposures; these studies comprise the bulk of Appendix A, a literature review. In addition some literature is reviewed that reports biologic studies using electromagnetic field exposures with characteristics different from EMP simulators. These latter studies were carefully selected for inclusion in this report because the exposures studied were believed to be applicable to EMP. A wide variety of exposure regimens are yet unexplored for possible application in the EMP data base. This discussion will address both public health concerns and potential issues arising from occupational exposures. Recommendations will be provided highlighting future research needed to more fully address the potential health effects related to electromagnetic fields associated with the operation of EMP simulators.

2. PHYSICAL PARAMETERS

In considering the question of human health effects from Electromagnetic Pulse (EMP), it is useful to review the physical characteristics of the pulse and its interactions with the human body, which is the objective of this section of the report. Very little bioeffects research has been performed using the particular exposure parameters which occur in the vicinity of EMP test facilities, especially when compared to the hundreds of experiments undertaken to investigate the biological effects of electromagnetic fields in general. Efforts to relate bioeffects research using other electromagnetic wave forms to possible EMP effects must be approached carefully because of the distinct differences in physical interactions as discussed in this section. A careful analysis of these interactions can provide insight into possible criteria for culling the wide range of electromagnetic exposure conditions to find experimental data pertinent to EMP exposures. Only a preliminary analysis is provided within this report. The purpose of this section is to illustrate a framework for initial comparison of bioeffects data and to point out areas in which further investigation may be useful.

2.1 EMP PULSE CHARACTERISTICS

Electromagnetic Pulse exposure facilities generate high intensity, short duration electric and magnetic fields in an effort to simulate the conditions which occur during a high altitude thermonuclear explosion. The wave form parameters (rise time, duration and amplitude) of the pulse

are important in evaluating exposure conditions. These parameters vary from one facility to the next because of differences in field generation equipment, but a general expression for the time domain wave form can be used to gain insight into interactions of the fields with biological systems:

$$E(t) = Eo \left[e^{-\alpha t} - e^{-\beta t}\right] \quad (1)$$

Eo is the peak amplitude and $1/\alpha$ and $1/\beta$ are the time constants of the pulse. The time to peak field strength can be found by setting the derivative of E to zero and solving for t:

$$t(peak) = \frac{1}{\beta - \alpha} \ln (\beta/\alpha) \quad (2)$$

Typical rise times for most EMP facilities are in the range of 10 ns, and pulse durations are about 1 μs.

A useful technique for examining pulsed wave forms such as EMP is to perform a Fourier transform of the pulse to reveal the frequency spectrum. This approach is important because electromagnetic interactions with a given object vary significantly with frequency. The Fourier transform of equation (1) is:

$$E(\omega) = \frac{Eo\ (\beta - \alpha)}{(j\omega + \alpha)\ (j\omega + \beta)} \quad (3)$$

$E(\omega)$ is a complex number representing the magnitude and phase of the electric field as a function of frequency. The magnitude of $E(\omega)$ is

$$|E(\omega)| = [E(\omega)\ E^*(\omega)]^{1/2} = \frac{E_o\ (\beta - \alpha)}{[(\omega^2 + \alpha^2)\ (\omega^2 + \beta^2)]^{1/2}} \tag{4}$$

where $E^*(\omega)$ is the complex conjugate of $E(\omega)$. The energy density as a function of frequency can be expressed as:

$$S(\omega) = \frac{|E(\omega)^2|}{377}\ \mathrm{J/Hz} \quad . \tag{5}$$

Finally, the normalized cumulative energy spectrum density is given by:

$$W_n(\omega) = \left(\int_o^{\omega} S(\omega)\ d\omega\right)/\left(\int_o^{\infty} S(\omega)\ d\omega\right) \quad . \tag{6}$$

The above equations provide much useful information about EMP pulses. Figure 2.1 is a plot of the generalized EMP wave form of equation (1) using values of $\alpha = 4 \times 10^6$/s, $\beta = 4.76 \times 10^8$/s and Eo = 50 kV/m. Note the fast rise time and relatively slower decay rate. Figure 2.2 shows the magnitude of $E(\omega)$ as a function of frequency from equation (4) along with the normalized cumulative energy density using equation (6). Most of the energy in the pulse occurs at frequencies below 100 MHz for these pulse parameters which produce a rise time on the order of 10 ns. As is evident from the above equations, the high frequency content of the pulse is directly related to rise time; faster rise times produce greater field strengths in the high frequency portion of the spectrum, resulting in a shift of relative energy content in the same direction.

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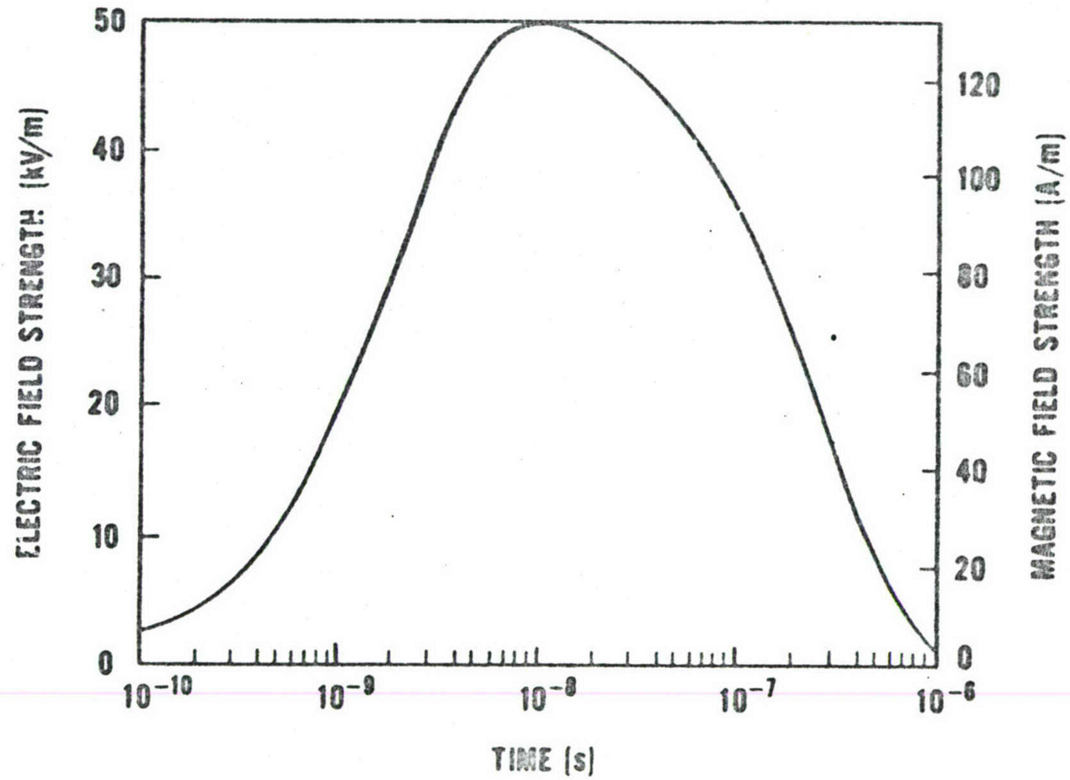

Fig. 2.1. Generalized EMP waveform using values of $\alpha = 4 \times 10^6$/s, $\beta = 4.76 \times 10^8$/s and Eo = 50 kV/m.

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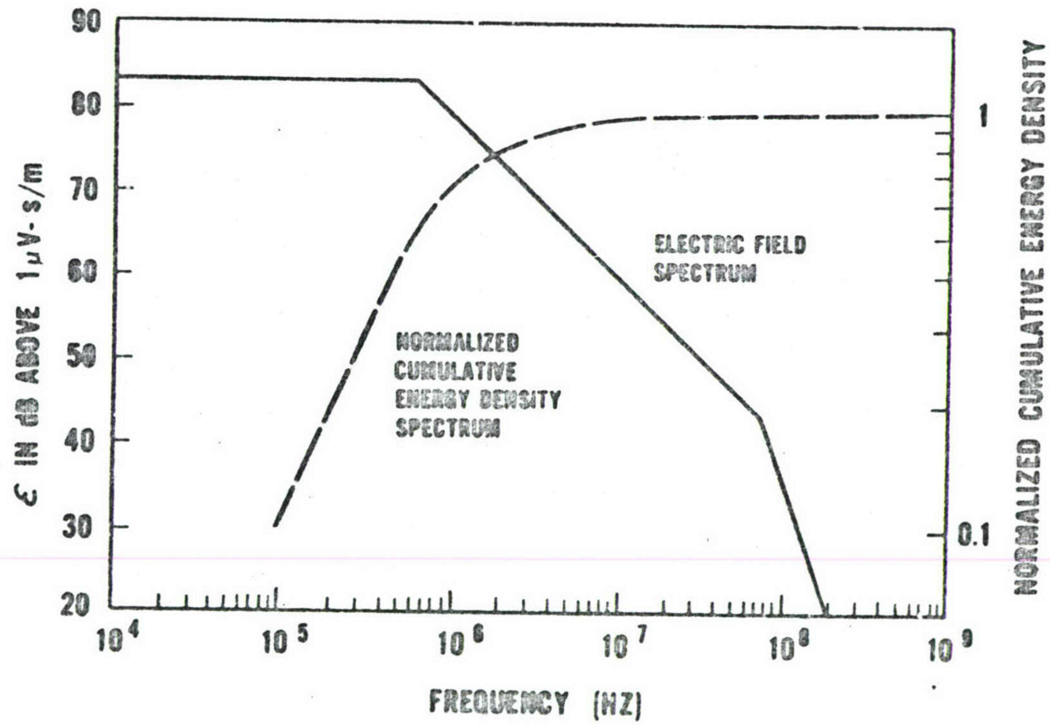

Fig. 2.2. Magnitude of $E(\omega)$ as a function of frequency and normalized cumulative energy density spectrum.

Design specifications for a proposed facility, VEMPS II, indicate that it will impress peak voltages of 6 MV on the VEMPS II antenna structure. Thus, near-electric fields of over 100 kV/m are likely. Human exposures are typically much lower because of distance and other attenuation factors. Near-magnetic fields depend on the current through antenna, and no simple expression for the relationship of near-electric to near-magnetic fields can be given for all points in space. In the far field, the electric and magnetic fields are related by $E/H = 377\ \Omega$, and both quantities vary inversely with distance from the antenna. VEMPS II is designed specifically to produce faster rise time pulses than existing facilities, and without specifically addressing the wave form and rise time to be used, it is clear that greater field strengths above 10 MHz will be generated than have been observed in other, slower designs.

2.2 ENERGY DEPOSITION IN HUMANS DUE TO EMP EXPOSURE

Although the peak field strengths produced by EMP simulators can be very intense, the total energy density is quite small because of the short duration of the pulse. Typical pulse widths are less than 1 μs, resulting in an energy density of about 0.9 J/m^2 for a peak field strength of 50 kV/m (see Appendix B). Even if all the incident energy were absorbed in the body, the resulting temperature increase would be minuscule (Bell Telephone Laboratories 1975). Such simple physical analyses have led many investigators to conclude that no adverse health effects resulting from EMP exposure are possible because the total energy involved is so low. This viewpoint is consistent with the longstanding belief that the only

adverse effects of nonionizing electromagnetic radiation are based on thermal interactions. Recent experiments involving calcium efflux and other phenomena, however, have demonstrated that field strengths below the nonthermal threshold are capable of producing effects. Such effects have been acknowledged in a report by the National Research Council (NRC) and further experimentation is under way (NRC 1986).

While it is clear that averaging absorbed EMP energy over the entire body results in a negligible temperature increase, the issue of localized heating or energy concentration should be considered. An interesting example is the microwave hearing effect in which low-level microwave pulses are absorbed in the head and transduced into thermoelastic stress waves which are audible to the subject (Polk 1986). This effect is well documented by researchers and microwave workers with energy densities as low as 0.04 mJ/cm^2 and subsequent temperature increases of only 5 millionths of a degree Centigrade. Such effects result from concentration of incident energy in localized areas and are dependent on geometry and the properties of the typically heterogeneous absorbing materials. The physical complexity of biological systems makes prediction of such effects difficult and only relatively simple models have been attempted (Lin 1980). The point made here is that all biological effects may not be predictable from simple energy calculations and in some situations the line between thermal and nonthermal effects may become blurred.

More research is necessary to adequately characterize the physical interactions of EMP fields with the body. Early work by Guy using a

spherical human model demonstrated that the time rate of change in intensity rather than pulse width governs the amount of energy coupled into the body (Guy 1975). This effect is due to increased energy absorption by the body at higher frequencies. Such efforts should be continued using more advanced human models developed in recent years, including prolate spheroids and ellipsoids. Guy has recently performed modeling of current distributions in a human model exposed to EMP fields (Guy 1988). Preliminary results indicate that extremely high average current densities (greater than 0.5 A/cm^2) are induced in small cross-sectional areas of the body such as the ankles. While the short pulse duration limits the total energy available, the path of these currents through high conductivity pathways such as the blood should be considered. Because of the low conductivity of bone as compared to blood and other tissues, even higher local current densities are expected. Once these currents have been adequately characterized, validating experimental approaches may be designed to study such currents in live blood and bone marrow. These currents may be quite different in laboratory animals when compared with humans because the current distributions in humans and small animals differ significantly for exposures to EMP fields. In any case, current distributions in humans exposed to EMPs of various rise times and field strengths should be determined.

2.3 DIFFERENCES IN EXPOSURE CHARACTERISTICS BETWEEN EMP AND OTHER ELECTROMAGNETIC FIELD BIOEFFECTS EXPERIMENTS

Major differences exist between EMP exposures and the exposure conditions used in most electromagnetic field bioeffects experiments. It is important to note these differences as well as any similarities in order to develop a basis for relating existing research results to the question of EMP effects. Such an approach is necessitated by the relative lack of experiments performed using EMP-type conditions. Direct prediction of potential EMP effects is presently not possible, because there is as yet no consensus among researchers as to mechanisms of interaction leading to nonthermal effects.

EMP simulators are unique in producing very-high-intensity exposures with high frequency content. Particularly notable is the nonperiodic nature of the pulses. Various EMP simulators are capable of generating pulses from several per second to one every several minutes. Most bioeffects experiments use either continuous wave or periodic pulsed wave exposures. At microwave frequencies, a carrier signal may be pulse modulated while at extremely low frequencies, field pulses may be repeated only a few times per second. Most of the nonthermal effects at low frequencies have been shown to be highly sensitive to the pulse repetition rate implying some type of resonance phenomenon or "window effects." Such a requirement would tend to exclude EMP exposures because of the lack of regular repetition rate and the long quiet period between pulses.

In general, the field strengths generated by EMP simulators are far greater than those used in either continuous wave or pulsed bioeffects

experiments except as noted later. The reason is directly related to energy considerations. The energy contained in a pulsed electromagnetic field is related to the duty cycle as well as to the amplitude. With even a few percent duty cycle, many EMP intensity fields would produce specific absorption rates (SAR) capable of cooking a biological specimen. For similar reasons, as well as limits to output power capacity, EMP intensity fields are not generated by most microwave devices. Nevertheless, EMP exposures can probably be more readily related to pulsed microwave exposures than other exposures because of the closer correspondence of rise times and pulse durations. Higher peak field strengths are also possible in pulsed systems because limited duty cycles can be used to hold SARs down to reasonable levels.

2.4 INTERNAL FIELD STRENGTHS PRODUCED IN HUMANS AND LABORATORY ANIMALS DURING EMP EXPOSURES

An important feature of EMP exposures is the high internal electric field strengths created during the pulse. This single factor differentiates EMP exposures from most other types of exposures from natural or man-made sources of nonionizing electromagnetic radiation. It also argues for the need for further analytical and biological research directed specifically at EMP exposures. Accurate determination of internal electric field strengths is a definite step towards establishing criteria for comparing EMP exposures to the existing bioelectromagnetics effects data base. Body tissues are ultimately exposed to the internal field strengths.

Internal electric field strengths depend strongly on the frequency, intensity, polarization and angle of incidence of the field, in addition to the geometry and electromagnetic parameters (conductivity, magnetic permeability and dielectric constant) of the subject. These internal electric fields are, in general, smaller than the incident electric field. Because the body is nonmagnetic, external and internal magnetic field strengths are essentially the same at low frequencies. At extremely low frequency (ELF), the skin effectively shields the body from electric fields so that internal electric field strengths are very low even for high external field exposures. The ratio of internal to external electric field strength at 60 Hz is approximately 4×10^{-8} (Polk 1986). This means that an external electric field strength of 50 kV/m at 60 Hz will produce an internal electric field strength of about 2 mV/m.

It is interesting to note that most of the early research into possible power frequency (50-60 Hz) bioeffects concentrated on pure electric field exposures because of the nonmagnetic nature of the body. This viewpoint overlooked the induction of currents and electric fields inside the body by the time-varying magnetic fields as well as any directly acting magnetic interactions (discussed further in Sections 4.1 and 4.2 of this report.) A magnetic flux density of 5 G at 60 Hz, for example, is calculated to produce an internal electric field strength of 10 mV/m using a path radius of 0.1 m and a conductivity of 0.11 S/m (Polk 1986). Recent bioeffects research investigating ELF magnetic field exposures has suggested that the magnetic component may be biologically

active (Wertheimer and Leeper 1979; Easterly 1981), although no single interaction mechanism has gained widespread acceptance.

The ratio of internal to external electric field strength increases with frequency up to body resonance, i.e., the frequency at which the absorption of electromagnetic energy by the body is maximum. The frequency of whole-body resonance depends on grounding conditions and body size for individuals aligned with the field and, for humans, generally falls between 30 MHz and 300 MHz (NCRP 1981). Above resonance, internal electric field strength falls below the resonant value and then remains relatively constant with increasing frequency. At microwave frequencies, the intensities of both the electric and magnetic fields are significantly attenuated as a function of depth into the body tissues. This attenuation is characterized by the penetration depth which varies between tissue types and depends to a large extent on water content. The penetration depth in high-water-content tissues such as skin and muscle is about 2 cm at 2.45 GHz.

The brief overview of field interactions given above provides insight into the question of internal field strengths resulting from exposure to EMPs. The extremely high field strengths generated during an EMP are far greater than any other exposures except at extremely low frequencies (ELF), very low frequencies (VLF), and some pulsed microwave systems. ELF and static electric field exposures often exceed 50 kV/m under high voltage power lines, but internal electric field strengths are small as shown earlier. Some VLF sources such as LORAN-C and OMEGA stations create peak electric field strengths greater than 1 kV/m in accessible areas but

internal fields are also highly attenuated at these frequencies (Gailey 1987). It is estimated that a peak electric field strength of 1350 V/m at 100 kHz (LORAN-C) will produce an internal field strength of about 50 mV/m. Similar internal electric field strengths are expected as a result of magnetic field induction near these facilities. Lightning is known to produce high field strengths but the rise times are typically around 100 ns (Weidman 1980), indicating that very little energy is produced near body resonance frequencies.

High field strengths are sometimes generated by pulsed microwave systems such as radar. The current American National Standards Institute (ANSI) exposure limit at microwave frequencies is 5 mW/cm^2 averaged over 6 min (ANSI 1982), but by reducing duty cycles, instantaneous peak powers can be much higher. A peak power of 10,000 mW/cm^2 indicates a peak field strength of 6 kV/m. It should also be noted that the rise times of such systems may be equal to or greater than that of EMP. The ratio of internal to external field strength from these pulsed microwave fields, however, is less than at resonance due to coupling effects, (NCRP 1981) and is further reduced as indicated by the penetration depth.

Using a spherical human model, Guy has shown that at frequencies below resonance but still in the megahertz range, internal electric field strengths are within an order of magnitude of incident EMP field strengths (Guy 1975). More recent analytical studies have examined the field strengths inside ellipsoid and prolate spheroid human models exposed to continuous wave fields near resonance (Barber 1977; Wu 1979; Durney 1980). These studies indicate that internal field strengths at resonance can be

more than half of the incident field strength. This effect becomes even more important for faster rise time pulses because of the resulting higher field strengths above 30 MHz in the resonant range. Thus, internal electric field strengths up to tens of kV/m can be expected to result from EMP exposures of 50 kV/m.

Most other exposures in the body resonance frequency range are far lower than those produced by EMP. The reason is that most sources in this frequency range are not operated at low duty cycles, and because of the efficient energy absorption, high field strengths would deposit excessive energy in the body. For example, the present electric field strength limit at 70 MHz set by ANSI is about 60 V/m while values a few times greater would result in known harmful thermal effects. EMP electric field strengths may reach values more than 100 times greater in terms of field or 10,000 times greater in terms of instantaneous power density. These values should not be confused with total energy which is limited by pulse duration as described earlier.

2.5 POSSIBLE IMPORTANCE OF INTERNAL FIELD STRENGTHS IN PRODUCING BIOEFFECTS

The generation of high internal field strengths as discussed in the previous section raises the question of whether or not such fields are important in producing bioeffects. This question is valid because humans do not appear to have evolved with any natural sources of electromagnetic radiation capable of producing such internal exposures with the possible exception of lightning. Other than EMP simulators there are also few

man-made sources from which to draw extensive exposure history or experience.

One argument against the possibility of EMP bioeffects is that the pulse duration is far shorter than the time frame of most biological processes. If certain energy thresholds are exceeded, however, it may be impossible for the body to ignore the stimulus. This situation may be analogous to the human eye viewing a star: the apparent stellar diameter is far too small to be resolved even in large telescopes but the incoming light is too intense for the light receptors in the eye to ignore. While the total EMP energy averaged over the entire body is far too small to produce significant effects, the questions of local intensifications, charge transfer, boundary layer effects, and local current densities have not been adequately addressed.

Microwave hearing and tissue layer resonance effects demonstrate that incident energy can be concentrated in local areas to produce otherwise unlikely events. Such effects are typically difficult to predict because of the complexity of body geometry but have been effectively modeled in some cases once they were identified. The question of charge transfer is important because of the possibility of rectification at membranes and boundaries. Biological structures are complex and may produce unusual electrical effects; membrane rectification has already been demonstrated at certain frequencies. Current distributions should also be studied because of the large differences in tissue conductivities and the physical extent of certain body structures such as blood vessels and nerves.

The very limited number of bioeffects experiments that have been performed using EMP-type exposures are described in the balance of this report. In general, the results do not indicate serious effects, but care must be exercised when evaluating the exposure aspects of these experiments. Particular concerns relate to the probable differences in internal field strengths and current distributions between the small exposed animals and man. Body resonance is determined by physical size and geometry; small laboratory animals such as mice and rats will resonate at much higher frequencies than humans. Because field intensity drops off rapidly at high frequencies for typical EMP exposures, very little energy is available at the small animals' resonant frequency. Consequently, the internal field strengths are less than would occur in humans under similar exposure conditions.

Induced current densities in laboratory animals are also likely to differ from those induced in humans. Several investigators have recently been examining current densities induced in small cross-sectional areas of the human body such as the ankles and wrists (Guy and Chou 1985; Gandhi et al. 1985). Total current is confined in these regions resulting in higher current densities. Obvious differences exist between humans and small laboratory animals in this regard.

Recent efforts to identify interaction mechanisms for electromagnetic field bioeffects have centered on cell membranes (Baywin and Adey 1976; Frohlich 1980; Bond and Wyeth 1986). It has been suggested that relatively weak stimuli at the membrane surface such as nonthermal electromagnetic fields may trigger events within the cell. Thus some

insight into the possibility of EMP bioeffects may be gained by estimating the induced membrane potentials. The induced values can then be compared with the natural membrane potential of less than 100 mV (Adey 1981).

Schwan gives the maximum field induced membrane potential as

$$Vm = \frac{1.5\ ER}{1 + j\omega T}\ , \tag{7}$$

where E is the electric field strength, R is the cell radius, and T is the time constant for the beta dispersion (Schwan and Foster 1980). The electric field strength, E, is that occurring inside the body tissue but outside the cell. Based on Schwan's model (Schwan and Foster 1980) the membrane potential can be estimated by substituting the Laplace transform of equation (1) into equation (7). Then, using a peak field of 10 kV/m, a cell radius of 10^{-5} m, and the beta dispersion time constant for blood ($T = 5 \times 10^{-8}$ s), the above model predicts a membrane potential of 50 mV. This value scales with field strength (i.e., a 20-kV/m field would induce a membrane potential of 100 mV).

Another approach to predicting membrane potential is to use the induced current density and membrane impedance. Schwan gives the example (Schwan and Foster 1980) of a 10-mW/cm^2 field flux at microwave frequencies (twice the ANSI limit). This exposure induces an internal field strength of about 100 V/m resulting in a current density of 10 mA/cm^2 because tissue resistivities are of the order of 100 Ω-cm. The induced membrane potential can then be found using equation (8):

$$Vm = \frac{J}{\omega C} \quad . \tag{8}$$

Here, J is the current density and C is the membrane capacitance per unit area (about 1 $\mu F/cm^2$). The above example yields a membrane potential of about 5 μV at 3 GHz.

Recent modeling of current induced in humans by EMP (Guy 1988) predicts values of 21.5 A for durations of 1 to 10 ns using an EMP described by equation (1) with $\alpha = 4 \times 10^6/s$, $\beta = 4.76 \times 10^8/s$, and $Eo = 1$ kV/m. For an ankle cross-sectional area of 40 cm and an $Eo = 10$ kV/m, this translates to an average current density of 5.38 A/cm^2. Applying this current density to equation (8) at 100 MHz yields a membrane potential of about 8.0 mV. A more reasonable approach, however, is to recognize the unipolar nature of the EMP. If the current density is assumed constant over some time period, then the membrane potential should be simply

$$Vm = \frac{Jt}{C} \quad , \tag{9}$$

where t is the time duration in seconds. Using the above current densities and a time duration of 10 ns, equation (9) predicts a membrane potential of over 50 mV. Higher values are predicted if the current pulse is integrated and the total charge applied to the membrane capacitance.

It appears from the above analysis that EMP-induced membrane potentials may be comparable to or greater than natural membrane potentials. The question now arises as to whether depolarization of the membrane or other perturbing interactions is possible in the extremely short duration of the pulse. Experiments with human red blood cells

demonstrate that breakdown of cell membranes occur at potentials of 1.6 V applied for about 20 μs (Zimmerman et al. 1974). It is not clear how pulse duration affects the breakdown potential. The above calculations used an incident EMP field strength of only 10 kV/m and a cross-sectional area of 40 cm^2. The highly conductive cross-sectional area of the ankle (excluding bone) is much less than 40 cm^2, and much higher current densities than those described here are possible. In a worst case calculation, one could assume an incident EMP of 100 kV/m and an effective cross-sectional area of 10 cm^2. For these conditions and the same field-current relationship, equation (9) predicts a membrane potential of over 2 V.

2.6 CONCLUSIONS

Exposure to EMP fields creates unique electrical conditions inside the body. The current densities and internal electric field strengths produced during EMP are substantially greater than those experienced as a result of other electromagnetic field exposures. The discussion provided in this section does not indicate any adverse biological effects related to EMP, but does serve to underline the importance of and need for careful analytical work to better characterize the physical interactions of EMP with biological systems. A thorough understanding of these internal exposure conditions will yield greater insight into the possibility of biological effects and provide the basis for more productive experimental approaches. Identifying these underlying physical interactions also

provides the immediate benefit of establishing criteria for comparing existing bioelectromagnetic data to the conditions occurring during EMP.

A careful examination of the EMP wave form along with biological characteristics at high frequencies can lead to the determination of parameters which can be used to identify pertinent biological data not originally intended for application to EMP. Implementation of this concept could greatly expand the scope of the analysis to be presented in Section 3. The value of this line of reasoning can be understood by contrasting costs of present-day whole animal laboratory experiments with costs of data analysis. Work to be reviewed in the next section has focused on laboratory data mostly taken nearly a decade ago using an EMP simulator for exposures.

3. BIOLOGICAL STUDIES

This section describes the status of research probing the possible human health effects associated with EMP exposures. A complete and detailed review of the experimental literature related expressly to EMP exposures is provided. This literature is largely pre-1980 because little research on EMP exposures has been performed in the last decade. Three non-EMP articles have been identified which contain sufficiently pertinent data for inclusion in the discussion. Finally, a synthesis is provided for the human (epidemiologic) data that may be relevant to occupational and public exposures.

3.1 *IN VIVO* EXPERIMENTS

3.1.1 Introduction

Studies sponsored by the U.S. military services are prominent in EMP research. Several early, exploratory studies were conducted to identify evidence of acute effects (Hirsh and Bruner 1972). Most notable, however, is a later series of experiments in which dogs and rodents (mice and rats) were exposed to extremely large numbers of EMPs. All experiments used the same exposure device, an Armed Forces Radiobiological Research Institute (AFRRI) EMP generator with a 5-ns rise time and a 550-ns 1/e fall time; this device provided 5 pulses/s at 447 kV/m peak (Skidmore and Baum 1974). Experiments included short-term bioassays designed to extend the early studies of acute effects; later, larger experiments expanded the

evaluation for possible carcinogenic and reproductive outcomes due to EMP exposures (Skidmore and Baum 1974; Baum et al. 1976; Baum 1979).

These experiments (see Table 3.1) were large, carefully controlled studies. The acute effects studies varied considerably in statistical power in the ability to detect differences between comparison groups, if they truly did exist (Table 3.1) (Steel and Torrie 1980). The carcinogenic and reproductive studies, and the experiments with dogs generally involved smaller sample sizes; accordingly they were less powerful statistically.

3.1.2 Discussion of Experiments

The following discussion of the experiments reviewed to date is in preparation for an assessment of potential EMP-related health effects. These are six of dozens of studies that may be eventually determined to have relation to EMP exposures (see Section 2). However, at this point in Subtask 1b, only these six were selected. The basis for selection was either (1) the express use of an EMP simulator for producing the experimental exposure, or (2) the use of a sufficiently similar exposure parameter that some clear relation to EMP-like exposure could be drawn. These experiments are discussed with attention to study design and biological parameters studied. Critiques are based on the limitations of the study interpretations, principally from a statistical standpoint

3.1.2.1 Armed Forces Radiobiological Research Institute

Observations of the exposed and nonexposed groups indicated that the exposed group's measured parameters were not statistically different from

Table 3.1. Comparison of selected *in vivo* experiments with exposure to EMP

Author	Parameter	Statistical power[a] for the observed finding (%)	Power to detect a 10% change (%)	Least detectable change with a power of 90% (%)
Skidmore and Baum 1974	Iron uptake			
	Low	74.54[b]	69.85[c]	19.9[d]
	High	42.07	97.93	16.6
	Chromosome	No difference	16.85	35.8
	Protein	No difference	98.50	8.7
	Albumin	44.43	71.90	14.1
	Calcium	No difference	96.08	9.3
	Phosphate	26.43	91.47	10.8
	Cholesterol	22.36	18.14	34.1
	Urea Nitrogen	16.85	55.57	17.1
	Uric Acid	16.11	5.05	111.1
	Creatine	99.88	70.54	14.3
	Bilirubin	No difference	32.28	23.9
	Alkaline phosphotase	2.68	8.53	60.8
	Reproductive substudy			
	Fertility	4.95	16 85	35.9
	Resorption	32.28	3.51	239.0
	Leukemic strain of mice			
	Thymus weight	14.46	6.18	84.7
	Spleen weight	14.69	4.36	144.6
	White blood cell count	99.99	15.62	3.8
Baum et al. 1976	Red blood cell count	No difference	73.89	13.8
	White blood cell count	5.16	19.77	31.3
	Neutrophils	4.36	7.21	68.3
	Leukocytes	12.92	24.83	27.9
	Reticulocyte	4.27	6.94	74.3
	Platelets	97.93	99.99	5.0
	4-Month-old males mated			
	Pregnancies	97.93	43.64	19.9
	Progeny	35.94	6.18	84.5

Table 3.1. continued

Author	Parameter	Statistical power[a] for the observed finding (%)	Power to detect a 10% change (%)	Least detectable change with a power of 90% (%)
Baum et al. 1976 (cont'd.)	24-Month-old males mated			
	Pregnancies	99.99	35.94	22.4
	Progeny	97.93	7.21	72.4
Baum 1979	Erythrocytes	7.21	31.56	24.3
	Reticulocyte	5.15	9.85	48.9
	Leukophils	5.16	42.47	20.3
	Neutrophils	5.16	63.31	15.6
	Lymphocytes	7.21	23.89	28.7
	Platelets	5.16	22.36	29.9
	Mitotic rubicytes	7.21	7.21	71.7
	Mitotic myelocytes	5.16	5.05	110.3

[a]Statistical power is defined as the ability to detect a difference between exposure groups (means), if that difference truly exists (Steel and Torrie 1980). A 90% power and the ability to detect a 10% change are common benchmarks in experimental research.

[b]If this experiment were repeated hundreds of times (with the same sample sizes and the same variability in the estimates), what would be the ability of those studies to detect the difference found in this one experiment, if that were the true difference produced by the exposure of interest. For example, using the exposed mean of 64.8 and the comparison mean of 72.4, the difference is 7.6%. If this were the true change in iron uptake due to EMP exposure, and this experiment were repeated many times, what percent of the tests would be expected to detect this effect? Answer: 74.54% of the tests would do so.

[c]Assuming that the "true difference" between experimental groups was 10%, this is the power for finding that difference. For example, assume that the true difference between means for iron uptake is 7.2% (e.g., 10% of the comparison means) instead of the 7.6% observed, what percentage of the replicate tests just like this one would be expected to detect that change? Answer: 69.85% of them could detect that change.

[d]Generally, a 90% level of statistical power is regarded as good. Numbers in this column reflect the amount of difference between the experimental groups which the study would be able to detect, if 90% power were a requirement of the study. For example, assume that a 90% power to detect a difference in mean iron uptake is required of the experiment. How large would that difference have to be in this EMP exposure group to achieve that requirement? Answer: 19.9% of the mean.

those of the nonexposed groups (see Table 3.1). The study results revealed no evidence of an adverse effect from exposure to EMP, even with lifetime exposures involving over 100 million pulses (Skidmore and Baum 1974; Baum et al. 1976). These animal studies were performed with exposures far in excess of the strength of EMP pulses to which humans may be exposed, either occupationally or through incidental public contact. Very little evidence of biological activity was observed and no evidence of adverse effect was reported (Baum et al. 1976; Baum 1979). A detailed description of the three focal studies follows:

(1) The first of the large scale experiments exposed 100 mice and 740 rats to 100 million EMPs of 447 kV/m; exposure conditions were 22 h/d, over 38 weeks (Skidmore and Baum 1974). Separate subgroups of the total exposed and comparison rodent populations were used for specific tests; exposure parameters varied somewhat by experiment, e.g., duration of study and frequency of tissue collection. Commercial outbred rodent species were used for bone marrow studies, as well as tests on blood chemistry and constituents, histology, and embryology. Female rats were studied for mammary tumor incidence. Inbred rodent strains, with specific genetic predisposition for leukemia, were used for studying the induction of leukemia (Skidmore and Baum 1974).

Twelve rats (six exposed and six unexposed) were utilized for bone marrow studies every two weeks after exposure began--i.e., serial sacrifice. Eight additional rats were used on an alternate

two-week schedule to study chromosome aberrations. The hematologic studies were performed with two groups of ten animals each (i.e., 20 exposed and nonexposed), one group in each category being used on alternate weeks. Separate groups of 30 exposed and 30 unexposed rats were used for taking measurements of radioactive iron (Fe^{++}) incorporation into erythrocytes. Additionally, complete blood chemistry studies were conducted with 5 each of the exposed and unexposed animals sacrificed for the bone marrow studies. Animals sacrificed for the bone marrow studies also had complete postmortem examination, including rigorous histopathologic studies.

Fetuses were irradiated during the gestation period of 5 rats, and subsequently were compared visually and histologically for congenital abnormalities to the litters for five not irradiated rats. Twenty each exposed and nonexposed female rats were observed for formation of mammary tumors. Forty-two leukemia-prone mice were irradiated; 24 nonirradiated mice of the same strain were used as controls. Leukemia incidence was assessed through 33 weeks of exposure.

Graphs of the serial study results were inspected for changes in trends or to detect patterns within the repeated measures. Simple t-tests were used to compare exposure groups for continuous variables (e.g., blood chemistries). No notable differences were observed over time for the bone marrow studies. With the reticulocyte counts, there were sporadic differences generally, with the exposed animal's counts elevated. The red blood cells showed no notable differences

over time. White blood cell counts indicated a few differences between exposure groups. In the case of the neutrophil counts there were two differences only, which occurred early in the exposure period. For lymphocytes, there were some differences between exposed and control groups; the pattern was for the exposed group to be elevated. Finally, with the serial platelet studies, there were many differences; and the exposed group's counts were lowered.

All of these results were defined as similar by the investigators. No increase in malformed fetuses, mammary tumors, or in any histological parameter was observed for the irradiated rats. No earlier or cumulative increase in the occurrence of leukemia was found in the predisposed mouse strain studied. The authors describe this series of experiments as representing an exposure "condition exceeding by several orders of magnitude that normally encountered by humans who operate EMP facilities" (Skidmore and Baum 1974).

(2) Subsequent to the preceding experiment, a replicate experiment was conducted with rats which were exposed to EMP for 94 weeks, beginning at four months of age (Baum et al. 1976). This large experiment studied 300 irradiated and 300 nonirradiated rats for chromosomal aberrations and changes in bone marrow cellularity. Animals were sacrificed over a 60-week schedule for the bone marrow studies; weekly comparisons of means were not consistently statistically different from one another. Data presented in the graphs of the serial measurements suggest that the reticulocyte counts show several changes early in the protocol, with the exposed groups generally

being elevated. With the platelet counts there are many differences between the groups; here the exposed levels are lowered.

The sacrificed animals were also examined for histologic changes in other tissues or organs. Blood chemistry studies were performed with 20 each exposed and nonexposed animals; complete counts of blood components were monitored throughout the exposure period. As with the preceding experiment, 20 each exposed and nonexposed female rats were examined specifically for mammary tumor formation. Reproductive effects were again assayed with the litters of five exposed and nonexposed matings. The authors reported "unequivocally" that there were no statistically significant differences between the exposure groups (Baum et al. 1976).

(3) Following the two large rodent studies, an EMP experiment was conducted with beagle dogs to evaluate a possible species difference for evidence of EMP health effects (Baum 1979). This experiment was designed expressly to simulate human, occupational exposure, e.g., 8 h/d for 45 d. Nine exposed and nine nonexposed dogs received complete blood and bone marrow studies beginning one week prior to onset of exposure and continuing through one year post irradiation. Four pregnant dogs (not members of the study groups of nine animals) were irradiated with the same exposure protocol during days 10-55 of gestation. Four pregnant animals served as a control group. The graphs of the serial hematologic studies, the erythrocytes, reticulocytes, leukocytes, neutrophils, lymphocytes, and platelets show no notable differences compared with the control animals.

As with the preceding experiments, no consistent or statistically significant evidence of differences could be detected between the exposure groups (Baum 1979).

3.1.2.2 Other experiments using EMP-like exposure

Several experiments have been conducted that may be germane to the potential of biologic activity from EMP exposure. In these studies, the researchers have uniformly eliminated heating artifacts so that the nonthermal impact of the electromagnetic energy may be studied. Three of these experiments are discussed below.

(1) Dutch rabbits were exposed to electromagnetic pulses for periods of up to 2 h in studies of phenobarbital-induced sleeping time and serum chemistry. The electromagnetic pulse was 1 kV/cm, pulsed over a range from 10-38 Hz; the rise time was 0.4 μs. These small studies were quite imprecise, in that only enormous differences between exposure groups could have been detected (see Table 3.2). All results of the research were interpreted by the authors as not indicating any EMP-related exposure effects. Body core temperature was measured to assure the absence of any heating effects, and no heating was observed (Cleary et al. 1980).

(2) Four rats conditioned to a time-modulated response behavior were systematically exposed to graduated levels of pulsed and continuous wave microwaves; power densities ranged from 1-15 mW/cm^3. A diminution of response was detected for rats exposed to the pulsed wave, however no change was detected for exposure via the continuous wave (Thomas et al. 1982).

Table 3.2. Comparison of selected *in vivo* experiments with exposures simulating some aspect of EMP[a]

Author	Parameter	Statistical power for the observed finding	Power to detect a 10% change	Least detectable change with a power of 90%
Cleary et al. 1980	Calcium	3.01	18.94	32.8
	Inorganic phosphate	99.99	99.88	7.0
	Glucose	99.99	99.99	1.1
	Alkaline phosphatase	74.86	42.47	20.4
	SGOT	18.67	4.01	176.7
	Total CPK			
	enzymes	9.01	10.56	50.6
	MM	85.31	25.14	27.8
	MB	3.29	7.78	66.7
	BB	22.66	4.65	126.5
	Sleeping time:			
	1.4 kV/cm 10 Hz	6.30	13.35	26.6
	1.9 kV/cm 24 Hz	10.93	14.46	40.0
	0.9 kV/cm 10 Hz	3.07	15.15	54.6
Thomas et al. 1982	Response rates are estimates from the graph for each of four animals		79.39	12.9
			27.09	26.6
			28.77	25.6
			78.81	12.8
Hamnerius et al. 1985	*Drosophila*	26.43	N/A	26.9
	Salmonella mutations			
	TA100[b]	95.35	N/A	9.8
	TA1535[b]	6.68	N/A	78.0
	TA1537[b]	7.93	N/A	65.5
	TA98[b]	16.11	N/A	37.0
	Salmonella survival			
	TA100	99.60	N/A	7.8
	TA1535	91.92	N/A	10.6
	TA1537	82.64	N/A	12.4
	TA98	88.30	N/A	11.3
	Pooled data	99.99	N/A	4.9

[a]See footnotes to Table 3.1.
[b]Different strains of *Salmonella typhimurium*.
N/A - Not available, data in article was incompatible with the calculation.

(3) A series of experiments was conducted to assess mutagenicity for several exposures to very high frequency electromagnetic fields. The 3.10 GHz portion of the experiments is of particular interest since this exposure has a 1 μs pulse width and is similar to an EMP. Both modulated and pulsed wave radiation were studied. Bacterial mutation was assayed with *Salmonella typhimurium* (the Ames assay), and somatic mutations with *Drosophila melanogaster* (common fruit fly). No evidence of increased mutations was observed in either system for any exposure configuration; however, improved colony growth was described for the exposed bacterial cultures (Hamnerius et al. 1985).

3.1.3 Summary of The Experiments Discussed Above

The results of the seven years of military-sponsored research provide a solid foundation for the investigators to infer no evidence of adverse health effects due to EMP exposures. However, the authors themselves point out the difficulty that exists with trying to "prove the absence of any injury" (Baum et al. 1976). This limitation must be recognized despite the considerable statistical precision achieved with some of the large experiments performed (see Table 3.1).

Using electromagnetic field conditions that are similar to EMP, other researchers have studied the serum chemistry, neurological and behavioral responses, and genotoxicity of electromagnetic radiation (Cleary et al. 1980; Thomas et al. 1982; Hamnerius et al. 1985). In the serum chemistry and neurological studies, the sample sizes were exceedingly small; only the most robust of biological responses could have been detected (Cleary et al. 1980). In the behavioral studies, the observed decrease in

response was associated with increasing power density and with signal type (i.e., pulsed wave) (Thomas et al. 1982). In the genotoxicity studies the research was more statistically precise, yet again, no evidence of adverse effects was detected (Hamnerius et al. 1985).

3.1.4 Critique and Synthesis of Results

The experiments directed to EMP exposures specifically have not reported any biologic effects of particular concern. The related electromagnetic fields studies also do not contain evidence of an overt biological effect associated with exposure conditions similar to EMP (Fletcher et al. 1987). However, experience with the history of a closely allied field of research, namely the extremely low frequency (ELF) electromagnetic field literature suggests strongly that there are three heuristic considerations when critiquing analyses: (1) statistical sensitivity for detecting small differences between exposure groups, (2) appropriateness of endpoints studied, and (3) the "cheshire cat phenomena."

Statistical Sensitivity. Comparisons of the means between exposed and nonexposed groups may have little statistical power (the ability to detect differences that truly exist), which may lead to a false impression of no difference due to exposure effects. To assess this characteristic, we have determined the statistical power (1 minus the beta error) for the calculations reported in the articles discussed above (Tables 3.1, 3.2). Not only does the difference between test means influence the sensitivity of a particular test, so does the sample size of the study groups, and the stability of the estimate. This latter attribute, the stability of the

estimate or standard error, is not a function of the sample size alone. The inherent variability in the data and the absolute value of the means (i.e., the coefficient of variation) are also important factors. Many of the comparisons utilized in the studies above offer an inadequate basis for the researchers to reject null hypotheses of no difference between test means (i.e., they have low power). The comparisons that have good power ought to be scrutinized most closely; it is those differences between means which are quite large, and are most likely to be biologically meaningful. Other differences of means for exposure groups may be large also, but due to the variability of the estimate can not be regarded as statistically significant.

Appropriateness of the Endpoints Studied. Many clinical parameters have been examined in EMP studies, as was done with the early ELF electromagnetic field studies. When many tests are performed with varying schedules (e.g., some weekly, some cumulative, some with different exposure parameters), occasional statistically significant differences are passed over. This is as it should be statistically. When results are interpreted at the $p < 0.05$ criterion, one of every 20 analyses will exceed this requirement due to random variation. In experiments where many tests are performed, as those described above, there is often a quandary over which results are really biologically meaningful, not only statistically significant.

Notably, the finding of lymphocyte elevation, and reticulocyte depression in two successive studies should now receive closer scrutiny (Skidmore and Baum 1974; Baum et al. 1976). This result is of concern in

light of the leukemia incidence associated with occupational exposures (Savitz and Calle 1987; Milham 1988; Dunphy 1988). Further, neurochemical markers recognized to be sensitive to electromagnetic stimulation (i.e., hormones secreted by the pineal gland, e.g., melatonin) have not been studied (Wilson et al. 1986). In addition, the improved growth rates for the bacteria in the mutagenesis assays, match provocatively well with the experience for tumor cells exposed to ELF magnetic fields (Phillips and Winters 1987). Finally, a decrease in pregnancies and progeny with EMP exposure is not detected with the small sample size, which has been a pattern reported for ELF exposures (Rommerin et al. 1987). These findings suggest the need to consider the potential similarities between the EMP and the ELF research programs and the similarities of the results for the first decade of studies for each respective exposure.

Cheshire Cat Phenomena. This pattern is widely known in the ELF literature, and shows its "smile" with EMP as well (Graves et al. 1979). The cited lymphocyte pattern with rodent studies does not persist in the dog studies. Sample size differences are an important consideration as are the experimental protocols. It should be noted that different rodents are used over time, but the same dogs are tested again and again (Skidmore and Baum 1974; Baum et al. 1976; Baum 1979). Additionally, for the rodent studies, many of the differences that are observed occur in the beginning of the exposure regimen; these differences dissipate later in the trial (Skidmore and Baum 1974; Baum et al. 1976). The potential for acclimation must be considered, which again was indicated by recent ELF research (Adey 1987).

These nuances are more than curious; they are scientifically troublesome. Workers exposed to EMPs are certain to also receive ELF exposures as well. The small amount of evidence which suggests that electromagnetic field exposures with extremely different exposure patterns may be exhibiting even mildly similar outcomes appears to warrant further consideration. One possibility for further work is the design of a set of experiments to address explicitly the potential for EMP versus ELF effects. Such a strategy would have the goal of determining whether there is evidence of a common response in biologic systems to electromagnetic exposures, or how the two exposures may be related and/or if their influence can be distinguished.

3.2 HUMAN RESEARCH

Another approach to assess the potential for health risk is the epidemiologic study of humans occupationally exposed to the agent of interest (Doll 1985). Both the military services and private industry have conducted such surveillance of employees exposed to EMP. These studies are discussed in the following section.

3.2.1 Introduction

No experimental studies have been conducted with humans. However, the basic animal research described above, the anecdotal experience associated with the manufacture of military simulators, and the military's own occupational studies reveal a consensus of opinion that the electromagnetic energy from EMP generally poses no human health risk (Glastone and Dolan 1977; Baum et al. 1976; LBERI 1977; OTA 1979; Lemer

1981; Broad 1981). There may be a slight health risk for persons with cardiac pacemakers; however, this is largely mitigated by engineering controls and restriction of access to facilities (Pickering 1973; LBERI 1977; Stewart 1978; NEFC 1984).

3.2.2 Occupational Exposures

During installation and acceptance testing of an EMP simulator, there will be workers inside and around the test facility. These workers (installers, testers) may be exposed to 10-50 kV/m fields. During typical operation, the worker exposures will range from 100 V/m to 50 kV/m (LBERI 1977). Most personnel associated with a facility are shielded from the electromagnetic fields by either the control buildings or the equipment being tested. For this reason, most exposures will be limited to field strengths around 100 V/m to 10 kV/m. The simulator recharges between firings, usually for 3-10 min, so that a "worse-case" exposure would be 160 individual pulses per day (e.g., 20 pulses/h x 8-h shift). Since repairs of equipment are performed by trained technicians, the risk of electrocution is minimal.

Levels of ozone from corona, or of sulphur hexafluoride, an insulating gas, are estimated to remain well below existing threshold limit values for occupational exposures (0.1 ppm and 1 part per 1000, respectively) (ACGIH 1986). Breakdown products resulting from corona or arc discharges in sulfur hexafluoride may be quite toxic (Griffin et al. 1984).

EMP simulators have been operating in the U.S. since the early 1960s. Long-term medical surveillance has been conducted with about 600 workers

at both civilian (Boeing Corporation) and military EMP facilities (Morgan 1988; Dunphy 1988; Peterson 1988; Mitchell 1988; Dancz 1988). Initial workers studies were performed by the Air Force on employees of EEG Corporation during the early 1970s (LBERI 1977; Giles 1988; Erwin 1988). Based upon medical examinations conducted for about two years, clinical parameters, hematology or acute symptoms presented no evidence of adverse health problems. Due to the lack of any apparent effects, the selective medical surveillance for military workers exposed to EMP was discontinued (Giles 1988; Erwin 1988; Morgan 1988; Dunphy 1988; Peterson 1988; Mitchell 1988; Dancz 1988). At this point, according to recent contacts, none of the U.S. military services have any ongoing surveillance programs for EMP exposed workers (Peterson 1988; Mitchell 1988; Dancz 1988).

Boeing Corporation has the only ongoing medical surveillance program for EMP-exposed workers in the U.S. that the authors have been able to identify (Morgan 1988). The Boeing system identifies all workers exposed to greater than 1 kV/m (below 1 kV/m is considered nonoccupational exposure). Workers exposed to between 1 and 5 kV/m are followed for identification of subsequent health problems and to ascertain cause of death. Only those workers who are exposed to greater than 5 kV/m are required to have routine medical examinations, in an effort to detect short-term health effects. All occupational exposures of 10-50 kV/m are monitored and logged; Boeing's corporate permissible exposure limit is 50 kV/m. With over 15 years of worker follow-up, including annual physical examinations, no adverse effects have been observed or reported among over 200 workers exposed to thousands of pulses. There have been

three cancers among the exposed workers, but this number does are not indicate an excess occurrence over the age, race and sex adjusted expected rates for the group, over the time period studied (Morgan 1988; Dunphy 1988). Due to no findings of any evidence of significant health effects among Boeing employees, and the company's excellent, ongoing radiation protection program, Boeing currently is considering the value of continuing its EMP surveillance program (Morgan 1988).

However, it is salient to this discussion to point out that all electrical occupations in Washington State have been the object of considerable research recently (Milham 1988). For several years, Washington State epidemiologist have been alerted to ecologic evidence of a generally increased risk of leukemia associated with occupations involving electrical exposures (Milham 1982; 1988). The finding of the three leukemia cases among Boeing's EMP workers has been included as a part of this larger Washington State research program (Dunphy 1988).

Bell laboratories has recently decided to increase its permissable exposure limit from 5 kV/m to 100 kV/M, the ACGIH standard (Peterson 1988). Bell Labs determined this change was acceptable, and additionally decided not to perform any distinctive medical surveillance for EMP workers, based on the absence of evidence of adverse effects from the Air Force and EEG studies (LBERI 1977; Peterson 1988). Likewise, surveillance for workers with other EMP facilities constructed since the OSHA review has not given cause to suspect any adverse effects (LBERI 1977; EMPRESS II 1987). At this time, the joint U.S. military services have convened a working group to consider the matter of possible human health risks from

EMP exposure and the potential need for an occupational standard (Hicks 1988).

3.2.3 Public Exposures

Operation of an EMP facility will result in very short pulses of relatively high electric fields near the antenna. Field strengths from an EMP simulator will probably be less than 1 kV/m in public locations. By contrast, field strengths of several thousand volts per meter (e.g., 5-10 kV/m) generally occur beneath high voltage transmission lines. However, the duration of the EMP electromagnetic fields is so brief and the repetition rate is so low that the possible effects for EMP fields cannot be directly compared with 60 Hz electromagnetic fields at this time. Any basis for comparison of effects will require thorough characterization of internal exposure conditions and an evaluation of possible interaction mechanisms. No effects on public health are expected to result from the operation of EMP simulator facilities. This assumption is based on the rapid attenuation of the electromagnetic fields away from the EMP simulator site, the presumed remote placement of the facility, and the restriction of access.

3.2.4 Summary of Human Studies

There has been a reasonable inspection of the evidence for possible human health risks associated with occupational EMP exposures. Both the limited human data and the experimental data suggest that if biological systems are affected by EMPs, the effect is small for the endpoints investigated and the biological systems tested. In view of the cumulative research through the mid-1970s, the Occupational Safety and Health

Administration determined that no safety standard was needed to protect worker health from exposure to electromagnetic pulses (Stender 1974, 1975).

By convention, the summary of the epidemiologic evidence to date may be addressed using Hill's criteria (Hill 1971).

(1) The strength of the association between EMP and adverse health effects is evidently small (despite the small sample sizes). Large increases in disease risk could have been detected with nearly 5000 person-years of exposure (assuming the combined interpretation of the military, Bell Laboratories, and Boeing surveillance systems). The 5000 person-years experience is sufficient to detect a 1.85 increase risk for an event occurring with a frequency of 5/1000, e.g., contact dermatitis (one tailed test with $\alpha = 0.05$ and $\beta = 0.10$). Similarly, an increased risk of 3.3 may be detected for an event occurring with a frequency of 1/1000, e.g., all cancer (same parameters: 1 tail, $\alpha = 0.05$. $\beta = 0.10$) (Schlesselman 1974).

(2) The specificity of the association is troubling. Based on the ELF literature, leukemia is an endpoint that has previously been associated with electromagnetic field exposures (Savitz and Calle 1987). The fact that leukemia is the endpoint of interest in the Boeing Corporation cohort (Morgan 1988; Dunphy 1988) provides specific agreement for the hypothesis. However, EMP and ELF exposures for the workers are probably concurrent. Further, the existence of a potential, generalized electrical occupational risk which is being studied in Washington State and the absence of

concordant hematologic experience between the military (EEG) and the Bell Laboratory cohorts lessens EMP's satisfaction of this criterion.

(3) Temporality is readily satisfied here, as it usually is; the surveillance for evidence of health effects manifestly followed the advent of EMP exposures.

(4) There is consistency of the epidemiologic finding across the three occupational groups studied, with the possible exception of leukemia as mentioned before. All of the cohorts, from different regions of the country, with different study populations, have shown no evidence of acute or short term health effects.

(5) The biologic plausibility of the absence of an EMP effect is good; this is based on the experimental data. However, the potential for a very subtle hematologic effect (e.g., the leukemia issue) is also biologically plausible (Aldrich and Easterly 1987). Based on residential ELF studies, the leukemia risk could be on the order of 1.69 for an event with a frequency of 0.0001. The experience of the combined cohorts (5000 person-years) would have a statistical power of only 34.5% for detecting that increase (Schlesselman 1982).

(6) The coherence (agreement) of the experimental and the epidemiologic data is very good. Both show the absence of any overt health risk. The potential for a subtle hematologic effect is likewise unresolved for both research programs.

(7) The presence of a dose-response relationship is not assessed for either program. From the ELF literature, there is reason to suspect

that a simple or classic relationship does not exist with electromagnetic field exposures (Adey 1987).

3.2.5 Critique and Synthesis of These Results

Considerable exploratory epidemiologic research with occupational exposures to ELF electromagnetic fields is already published (see Appendix C; Savitz and Calle 1987; Aldrich and Easterly 1987). This literature points directly to the possibility of a leukemia or brain cancer risk for exposure to electromagnetic irradiation. A yet unpublished work indicates that many occupations have exposure to intense ELF fields; and these occupations are not always the ones that may be considered intuitively to have those exposures (Bowman 1988). These data raise the question of which occupational groups have the greatest exposure, thus complicating the synthesis of the EMP occupational studies.

The fact that residential exposures, and even routine office exposures to electromagnetic fields (usually considered to be mild by industrial comparisons) may also be indicated as having adverse health effects further muddles the interpretation of EMP exposures (Aldrich and Easterly 1987; Foster 1986). Simply stated, the appearance that several experimental studies and considerable occupational experience have resolved the EMP health effects question is misleading. The potential for very rare health effects and the possibility of public health impacts will eventually have to be addressed more fully for EMP simulators.

Two approaches to the need for additional information regarding human exposure to EMP may be explored. First, an occupational surveillance system can be developed to build on the existing exposure experience (EEG

Corporation, Bell Laboratories, Boeing Corporation and military workers). This system would put into place statistical methods for making decisions about possible increased health risks as soon as possible (Aldrich et al. 1986; Glasser 1986; Rutstein et al. 1983). Such a sentinel event-based health surveillance system would represent a sound occupational health strategy, directed to the protection of all EMP workers (Finucane and McDonough 1982; Joyner and Pack 1982; Judd 1982; LeBlanc 1982).

The person-years of experience that would need to accrue with such an occupational surveillance system have been calculated (see Table 3.3). These data indicate that for events having the frequency of leukemia (1/10,000), 82,245 person-years of experience would be needed to detect a tripling of the risk due to EMP exposure (Schlesselman 1982). There are many considerations with respect to this approach that could advantage its usefulness, e.g., the development of a standard comparison group for such applications by the National Institute of Occupational Safety and Health (Thomas et al. 1986).

One step toward determining the efficacy of such a surveillance system could be the re-analysis of the existing occupational exposure data. This accumulated experience could be re-analyzed using recently recognized statistical techniques that have enhanced sensitivity for detecting increases in adverse health event occurrence, i.e., Poisson distribution and nonparametric statistical methods (Aldrich et al. 1986; Kleinbaum et al. 1982). This step alone could be quite useful for evaluating the potential occupational health risk posed by EMP exposure.

Table 3.3. **Sample size requirements for a potential epidemiologic study of EMP exposed workers**

Level of risk to be detectable	Background frequency of the endpoint			
	0.0001	0.001	0.005	0.01
1.2	4,689,002[a]	468,434	93,272	46,377
1.5	852,531	85,155	16,944	8,418
2.0	255,751	25,538	5,075	2,517
2.5	132,607	13,238	2,627	1,301
3.0	82,245	8,507	1,686	834

[a]These numbers are for each of the exposure groups (e.g., two groups of this size would be required for an exposed group versus a control group study. Also, these numbers may be regarded as person-years, e.g., ten people who are studied over ten years time contribute 100 person-years.

Also, work could be performed to assess the feasibility of ecologic epidemiologic studies of residents of communities living near EMP simulator facilities. Significant resources exist for the conduct of such studies, e.g., state-operated, population-based disease registries (Aldrich et al. 1988; Houk and Thacker 1987). EMP facilities are useful for this purpose, since the simulators are usually remote point sources and their exposure patterns may be accurately mapped. A similar strategy is currently being used by the National Cancer Institute to assess the potential public health risks from residential proximity to nuclear reactors (Boice 1988). Such investigative steps as these could make many contributions toward reconciling the potential questions regarding EMP simulator facilities.

4. PERSISTENT QUESTIONS ABOUT ELECTROMAGNETIC FIELDS

Since the late 1970s, a large amount of electromagnetic field literature has developed for 60-Hz fields, low-frequency pulsed fields (e.g., 10-50 pulses per second), radio frequency, and microwaves. The principal commonality among these forms of electromagnetic energy is that they all can induce electric currents in exposed persons and provide artificial electric and magnetic fields within the body. The uncertainty in exposure-response relationship has given rise to considerable scientific and public questioning about electromagnetic field exposures (Aldrich and Easterly 1987; Foster and Guy 1986; Foster and Pickard 1987; Banks 1988).

Biological activity (evidence of an effect) has been observed in studies of pulsed electrical fields from medical devices and from *in vitro* experiments with ELF fields (AIBS 1985; Aldrich and Easterly 1987). Principally, these studies examined cellular level effects, and have found evidence of biologic activity, but no overt, adverse effects (Cleary et al. 1980; Cain et al. 1985; Cain and Luben 1987; Lyle et al. 1985; Albert et al. 1985; Goodman and Henderson 1985; Bassett and Moran 1985; Hellman et al. 1985). Much medical research has been focused on the beneficial effects of these pulsed electromagnetic fields (PEMFs), which have been found to augment bone healing and nerve regeneration (Wilson and Jugadeesh 1976; Raji and Bowen 1983: Becker 1984). Similarly, work with high intensity 60-Hz electrical fields, radio frequency, and microwave fields has shown these exposures to have some biological activity, but no usually agreed upon detrimental effects other than heating effects (AIBS 1985; EPA 1984).

The possibility of EMP effects on ecologic systems (e.g., wildlife, endangered species, etc.) is a matter for considerable investigation (Drobeck 1987; Van Heukelem 1987; Hocutt and Nemeth 1987; Wiley 1987; Byrd and Wallin 1987; Cardano 1987). Based upon evaluation of the Navy's EMP facility over water, there is negligible impact on marine life or water fowl. Similarly, the effect on migratory birds or nesting species is considered minimal if existent at all. There is no potential for electrocution to birds perched on the antenna (Johnson 1987). Microscopic life, is similarly deemed to be safe in the immediate field of an EMP facility (Tsai and Millsaps 1987).

At present, the greatest evidence for potentially harmful effects of nonionizing electromagnetic energy derives from the epidemiology literature (human studies) (Werthemier and Leeper 1979; McDowall 1986; Savitz and Calle 1987). These studies indicate a small cancer risk (about a doubling for rare cancer types) possibly being associated with residential level exposures to electromagnetic energy (Aldrich and Easterly 1987). The principal hypothesis for any possible effects from these exposures is related to the presence of magnetic fields (Easterly 1981). The manner of the exposure is pivotal in distinguishing any appearance of possible health effects from EMP, based upon available evidence using extremely low frequency fields. EMP exposure to humans is intermittent, usually with several minutes intervening between pulses contrasted with ELF which cycles 60 times per second. Physical characteristics of the two exposures result in very different characteristics of induced currents in humans. Additional research is required to adequately test this hypothesis for electromagnetic field exposures (Aldrich and Easterly 1987). The uncertainty with the extremely low frequency exposures is in many ways due to the nature of the research that has taken place to

date. Such research has often been directed away from a realistic human exposure (Easterly et al. 1987). EMP research has not taken this "ivory tower" approach. In many respects, despite the lesser amount of total research, the EMP issue of health effects has been more adequately addressed than ELF. However, as mentioned earlier in this report (Section 3.1.4) several factors in research design must be carefully considered in order to minimize possible misinterpretations of the EMP data.

4.1 STUDY DESIGN CONSIDERATIONS

Research of possible health effects from ELF electromagnetic fields began with a strategy of pure phenomenology. Small, tightly controlled experiments were performed with intense scrutiny. This approach was intended to identify a method of action, should any effect be observed. For many years the ELF research pursued this path, with elaborate exposure facilities and very few test animals (Easterly et al. 1987). Occasionally an effect would be seen, but upon replication it would not appear. This frustrating circumstance became known as the "Cheshire Cat Phenomena" (Graves et al. 1979). Subsequent research has indicated that small effects were in fact occurring, but that the small sample sizes of the experimental units were actually obscuring the findings (Morris et al. 1988).

With a change in exposure parameters to include magnetic, not only electrical fields and the identification of sensitive biological systems, the reporting of effects (not necessarily adverse ones) began to occur more frequently. For many years ELF research focused on behavioral effects, blood chemistry and acute responses; later studies have explored chronic effects and more subtle cellular changes. The shift in productive findings may be related to two considerations,

(1) the selection of more human-like exposure parameters, and (2) the study of the endpoints of interest. EMP research has not suffered from these fallacies, because exposure conditions were designed to be very much like the human situation. Further the endpoints studied were exactly those of occupational and public health interest. The contrasting of ELF and EMP research initiatives continues below.

4.2 EXPOSURES OF INTEREST

Initial research interest with ELF fields was directed to pure 60 Hz electric fields, given over protracted periods of time. In early experiments, engineering controls were used to eliminate the magnetic component of the exposure. The experimental exposures were maintained within rigidly specific windows and did not permit mixed exposures which are characteristic of the human situation. The magnetic component was later determined to be the exposure of possibly greater interest; research was subsequently modified to simulate more human-like circumstances, e.g., mixed electric and magnetic fields. EMP research has always studied the combined electric and magnetic field which human operators of EMP simulators would experience. However, as with ELF research, EMP exposures have been carefully directed to exposure extremes. Recent discussion from ELF studies suggest that protracted, very intense fields are readily distinguished by living cells, producing acclimatization to the extremes of exposure. This theoretical biologic process would suggest that it is the lower intensity fields delivered intermittently that may produce a biologic response (not necessarily an adverse effect) (Adey 1987).

4.3 ENDPOINTS OF INTEREST

The principal human health effects of concern for public or occupational health generally are cancer and reproductive effects. These chronic impacts have been assessed for EMP exposures, and with experimental sample sizes of appropriate proportions in some studies. These studies put policy makers in a position to respond to risk management decisions by providing research data for EMP-related actions. There is even epidemiologic (surveillance) data for EMP with the assurance that valid exposures for the occupational groups studied were examined (e.g., Boeing, EGG and Air Force workers). Chronic endpoints of concern have been studied (e.g., mortality and morbidity analyses, as well as possible acute and short-term effects based on routine medical exams) (Morgan 1988).

These research conditions are not the case for ELF however, and that is frequently the exposure of interest to the public. While cancer and birth defects have been assessed in an ecologic manner for ELF exposures, there is considerable controversy about the nature of the exposure studied and its role with respect to the endpoints investigated.

4.4 RESIDUAL DILEMMAS

The public experiences an information and credibility gap with regard to data related to environmental hazards (Ruckelshous 1984). This residual dilemma applies to electromagnetic fields data. The public has many misconceptions about nonionizing radiation, and does not always recognize the distinctions across the frequency spectrum. Private citizens are likely to be resistant to accepting as harmless a force that they view comparable with microwave ovens and electrical shocks. There is a large area of uncertainty related to the mixed exposure that

comprises the "average" electromagnetic environment. Providing an accurate characterization of "normal" and "safe" exposure is a significant research need. A basis for understanding and describing the relative characteristics of different electromagnetic fields is needed and represents a tangible gap in the research literature.

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APPENDIX A

BIOLOGICAL EFFECTS OF EMP:

A LITERATURE REVIEW

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INTRODUCTION

A comprehensive literature search was conducted on the subject "biological effects of electromagnetic pulse (EMP)" utilizing several computerized systems.

The DIALOG system was searched by the ORNL Central Research Library (CRL) staff. Data bases accessed (with publication date ranges) were:

INSPEC, 1969-OCT 1987
MEDLINE, 1966-OCT 1987
NIOSH, 1973-OCT 1987
COMPENDEX, 1970-OCT 1987
ENGINEERING MEETINGS, 1984-OCT 1987
LC MARC, 1979-OCT 1987
BIOSIS PREVIEWS, 1969-OCT 1987
STANDARDS AND SPECIFICATIONS, 1950-OCT 1987
DOE ENERGY, 1974-OCT 1987
NUCLEAR SCIENCE ABSTRACTS, 1948-OCT 1987

The Defense Technical Information Center Technical Reports Data base (1978-OCT 1987) was also searched by CRL staff. TOXLINE (1965-NOV 1987), a MEDLARS data base, was searched by ORNL Health and Safety Research Division staff. Several recently published journal articles were retrieved by regularly scanning journal contents pages appearing in weekly issues of *Current Contents-Life Sciences*. Several articles were identified from reference lists of primary articles or by discussions with other researchers.

The search strategy was designed specifically for each online system to retrieve those references related to any biological effect from any type of electromagnetic pulse radiation. The resulting printouts were analyzed, and references of specific interest were collected. The authors of this document prepared an abstract for each reference which had no author abstract--these are marked with an asterisk (*) at the end of each such abstract in this bibliography. Some abstracts were taken from the report by J. J. Taylor, *Data base: Biological Effects of Electromagnetic Pulse*, Woodbridge VA: Harry Diamond Laboratories (1987). These are marked with "HDL" at the end of the abstract.

The online searching was accomplished with IBM Personal Computers (PCs) using PCTalk software (CRL staff) or Crosstalk software (Division staff) connected through Hayes Smartmodem 1200's to the remote systems. The bibliographic data base was prepared using WordPerfect software running on various IBM PCs.

The data base contains the following fields for each record:

AUTHOR
YEAR
TITLE
SOURCE
ABSTRACT

AUTHOR	Advisory Group for Aerospace Research and Development.
YEAR	1975
TITLE	AGARD Lecture Series No. 78 on Radiation Hazards.
SOURCE	NTIS Report No. ADA015200; AGARD-LS-78, 146 pp.
ABSTRACT	Devices utilizing or emitting non-ionizing radiation are used for military, industrial, telecommunications, medical, and consumer applications. Although there is some information available on biological effects and potential hazards to man from exposure to this type of radiation, considerable confusion and misinformation exists in public and scientific publications. Much of this confusion results from a misunderstanding of the fundamentals of energy-tissue interaction, threshold phenomena, personnel exposure, and product emission standards. This series of lectures provides a scientifically accurate, authoritative review and critical analysis, by experts in the field, of the information available at the time to provide a basis for informed judgements.*

AUTHOR	Anonymous
YEAR	1986
TITLE	Guidelines for an EMP Human Health Monitoring Program Plan.
SOURCE	Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Appendix EE, 4 pp.
ABSTRACT	In response to the issue of human health monitoring for exposure to EMP, and since OSHA has no current nor proposed standards regarding free field environments for single pulse EMP radiation, these guidelines reference OPNAVINST 5100.23 B "Navy Occupational Safety and Health (NAVOSH) Program" of 31 August 1983, with some modifications. The maximum permissible exposure is now 100 kV/m; six documents are referenced in support of this value. A representative document, DNA 4397F, is quoted as stating that "no adverse health effects were identified which could be attributed to EMP exposure"; this report was based on over 20 pulser projects over a period of 10 years. These guidelines delineate the modifications to the referenced standard that are necessary to adapt the standard to EMP radiation. These modifications are enumerated in four sections: medical surveillance, overexposure treatment, overexposure reporting, and overexposure procedures.*

AUTHOR Baum, S. J.
YEAR 1979
TITLE Tests of Biological Integrity in Dogs Exposed to an Electromagnetic Pulse Environment.
SOURCE *Health Phys.* 36(2):159-165
ABSTRACT Dogs were exposed to an electromagnetic pulse (EMP) environment 8 hr each day for 45 days. At the end of that time they had received 5.8 x 10xE6 EM pulses at 5 pulses/sec, with a peak electric field intensity of 447 kV/m. Biological tests were conducted to ascertain concentration of erythrocytes, leukocytes, neutrophils, lymphocytes, reticulocytes, and platelets. Bone marrow samples were obtained by biopsy from the ribs 7 days before and 7 days after the last EMP exposure for assessment of mitotic rubricytes and myelocytes. Pregnant female dogs were exposed to the EMP environment in order to study possible gross effects on fetuses. Reproductive capabilities of irradiated male animals were tested for 1 yr after the last exposure. None of these tests revealed any injury in the EMP-irradiated dogs. (AUTHOR ABSTRACT)

AUTHOR Baum, S. J.; Ekstrom, M. E.; Skidmore, W. D.; Wyant, D. E.; Atkinson, J. L.
YEAR 1976
TITLE Biological Measurements in Rodents Exposed Continuously Throughout Their Adult Life to Pulsed Electromagnetic Radiation.
SOURCE *Health Phys.* 30(2):161-166
ABSTRACT Rodents were exposed continuously for 94 weeks of their adult life to a total of 2.5 x 10xE8 pulses from the AFRRI electromagnetic pulse (EMP) simulator which provides 5 pulses/sec with a peak electric field intensity of 447 kV/m, a 5-nsec rise time and 550-nsec 1/e fall time. The following biological parameters were measured: blood chemistry, blood and bone marrow cellular concentration, chromosomal aberrations, erythrocyte production, effects on fertility and reproductive capability and appearance of tumors and other late effects. At no time before and particularly as the rodents approached the end of their life-span did any of the biological measurements indicate an effect of the EMP radiation. While it is extremely difficult to prove the absence of any injury, it can be unequivocally stated that EMP exposure presented no biological hazard to the rodents of the present study. (AUTHOR ABSTRACT)

AUTHOR Baum, S. J.; Skidmore, W. D.; Ekstrom, M. E.
YEAR 1973
TITLE Continuous Exposure of Rodents to 10xE8 Pulses of Electromagnetic Radiation.
SOURCE NTIS Report No. AD775217; AFRRI-SR73-23. 13 pp.
ABSTRACT The experiment tests the hypothesis that rapid rises and falls of electric and magnetic fields would adversely affect vital ionic and electrochemical processes at the molecular level in biological systems. Rodents were exposed to 10xE8 pulses from the AFRRI electromagnetic pulse (EMP) simulator which provides five pulses per second with a peak electric field intensity of 447 kV/m, a 5-nsec rise time and 550-nsec 1/e fall time. When results obtained from EMP exposed animals were compared with those from controls no changes were observed in the number and production of rat bone marrow cells, the concentration of circulating neutrophils, lymphocytes and erythrocytes. Reticulocytes appear to have been elevated and platelets decreased; however, both counts remained within acceptable levels. No incidence of mammary tumors was observed in the female Sprague-Dawley rats. In leukemia-prone AKR/J male mice, leukemia did not occur earlier in EMP exposed animals, nor was the fraction of leukemic mice greater in this group when compared with the nonirradiated control mice. (MODIFIED AUTHOR ABSTRACT)

AUTHOR Bell Laboratories
YEAR 1975
TITLE EMP Engineering and Design Principles
SOURCE Whippany, N.J.: Technical Publication Dept., Bell Laboratories
ABSTRACT The personal safety chapter of this technical manual discusses subjecting equipment to high voltage electric pulses or intense electromagnetic pulse fields. Electric shock is a hazard in the pulse fields due to metal objects which carry induced currents. Information on EMP is limited, but studies of radiofrequency radiations show that some radiations with frequency ranges similar to EMP can cause a harmful rise in body temperature. EMP is neither CW nor pulse-modulated CW because almost all of its energy is outside the frequency range. The thermal effect of EMP is negligible. Historical studies of persons working with equipment simulating EMP fields from 1 to 100 kV/m at Bell Labs reported no adverse effects. At Los Alamos Electromagnetic Calibration Simulator and at the Advanced Research Electromagnetic Simulator facilities, people were exposed to peak fields of 50 kV/m and did not report a case indicating adverse effects. Persons at Air Force Weapons Laboratory EMP branch were found medically normal. A variety of animal tests were conducted, but no significant changes were observed due to EMP. There is a danger from electric field shock, but this danger can be minimized by using safety guidelines.(HDL)

AUTHOR Bernhardt, J.
YEAR 1979
TITLE The Direct Influence of Electromagnetic Fields on Nerve- and Muscle Cells of Man Within the Frequency Range of 1 Hz to 30 MHz.
SOURCE *Radiat. Environ. Biophys.* 16(4):309-323
ABSTRACT By using several biophysical approximations and considering man as free space model, limiting order-of-magnitude values for external electric and magnetic field strengths which may be hazardous for human beings were calculated. Danger may occur by excitation processes below 30 kHz for field strengths exceeding these limiting values; for frequencies larger than 60 kHz, thermal effects are predominant before excitation occurs. The external electric field strength necessary for causing action potentials in the central nervous system exceeds by far the corona-forming level. But excitation is possible by strong alternating magnetic fields. Furthermore, by comparing the electrically and magnetically induced currents with the naturally flowing currents in man caused by the brain's and heart's electrical activity, a "lower boundary-line: was estimated. Regarding electric or magnetic field strengths undercutting this boundary-line, direct effects on the central nervous system may be excluded. Other mechanisms should be responsible for demonstrated biological effects. (AUTHOR ABSTRACT)

AUTHOR Boeing Company
YEAR 1987
TITLE Joint Government/Industry Conference on the Question of Occupational Exposure to Electromagnetic Pulses (EMP) and Potential Biological Effects.
SOURCE Conference Held at the Boeing Company, Kent, Washington, June 17-18, 1987. (approximately) 150+ pp.
ABSTRACT This conference was held to facilitate information exchange on the health and safety aspects of EMP radiation. The existing Department of Defense and occupational exposure limits of less-than-or equal-to 100 kV/meter were acceptable to the attendees. Research has not revealed any confirmed adverse biological effect from EMP exposures. A final consensus indicated that more research and continuing information exchange is needed to support current exposure standards and to provide data for future rule-making.*

AUTHOR Bond, J.; Dancz, J.; Nichols, B.
YEAR 1987 (Jan. 16)
TITLE Preliminary Record of Environmental Consideration, VEMPS II
SOURCE Science Applications International Corp., McLean, VA
ABSTRACT A literature review of available literature through 1983 was conducted for the U.S. Navy EMPRESS II Draft Environmental Impact Study to determine the effect of EMP on human biological and/or physiological responses. Field strength exposure limits were investigated. Electromagnetic energy from VEMPS II pulses was compared to the electromagnetic energy studied in literature. Electromagnetic coupling to biological systems was investigated. Bioeffects studies for humans exposed to EMP were summarized. EMP biological effects on fish and birds were also discussed. The differences between EMP and other types of nonionizing radiation were highlighted. (HDL)

AUTHOR Brodeur, P.
YEAR 1977
TITLE The Zapping of America
SOURCE New York: W .W. Norton and Co., Inc.
ABSTRACT Chapter 20 of this book deals with the effects and standards for EMP. Studies cited include the work of Baum et al. in the 1970's. There are many accusations and many innuendos about EMP as well as microwave radiation being dangerous, but no scientific studies to show cause and effect relationship. Brodeur implies that the leukemia studies were triggered by the onset of leukemia in Boeing employees and others exposed to EMP in Montana. Mention is made of a study just beginning about blood chemistry and sleeping time of rabbits. (HDL)

AUTHOR Bruner, A.
YEAR 1977
TITLE Review of Occupational Safety and Health Aspects of Electromagnetic Pulse Exposure.
SOURCE NTIS Report No. ADA053394; DNA-001-73-C-003. 22 pp.
ABSTRACT This report describes the nature of the typical occupational exposure to electromagnetic pulses (EMP) received by personnel working at EMP simulator facilities and summarizes the medical surveillance observations collected on those personnel. Data from both informal observations and from comprehensive annual physical examinations of approximately 600 workers exposed to various EMP's over a number of years disclosed no adverse health effects attributable to EMP exposure. It was concluded that sufficient no-effect findings from both the human and animal experiences now exist to confidently allay fears of an EMP worker exposure hazard, at least for within a 10-year observational time frame. (AUTHOR ABSTRACT)

AUTHOR Brunhart, G.; Carter, R. E.; Valencia, V. I.
YEAR 1973
TITLE AFRRI Electromagnetic Pulse (EMP) Simulator
SOURCE NTIS Report No. AD770113; AFRRI TN73-14. 12 pp.
ABSTRACT An electromagnetic pulse simulator for animal studies has been built and operated at AFRRI since September 1972. The exposure volume consists of a terminated parallel-plate transmission line fed with a pulse the time dependent wave form of which can be approximated by a double exponential. Peak electric field strengths up to 500 kV/m are available at a repetition rate up to 7 pps. (AUTHOR ABSTRACT)

AUTHOR Byrd, M. A.; Wallin, D. O.
YEAR 1985
TITLE Comparison of Reproductive Success of Ospreys Along the Patuxent River with that of Ospreys from the Virginia Portion of Chesapeake Bay.
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix Q, 27 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT The available data suggest that EMPRESS I has had no significant impact on osprey reproductive success along the Patuxent River in Maryland. This conclusion is consistent with the following hypotheses. 1. EMPRESS I has not been in operation during critical portions of the breeding season. 2. The effective range of EMPRESS I emissions are very short and have therefore had no effect on osprey productivity. 3. The power output of EMPRESS I is low enough to have had no effect on osprey productivity. 4. The electromagnetic pulse generated by an EMPRESS-I-type facility does not affect the reproductive output of ospreys. (MODIFIED AUTHOR ABSTRACT)

AUTHOR Cleary, S. F.
YEAR 1975
TITLE Investigation of the Biological Effects of Pulsed Electromagnetic Fields. Annual Progress Report No. 1.
SOURCE NTIS Report No. ADA093296. 18 pp.
ABSTRACT Research conducted has involved an investigation of the effects of electromagnetic pulsed fields (EMP) on the Dutch rabbit as well as *in vitro* study of electric field effects on bilayer lipid membranes (BLM). The object of the research is to determine the *in vivo* effects of EMP exposure and to develop model systems to investigate the basic mechanisms of interaction. Since extensive data on the biological effects of another type of electromagnetic stressor, namely microwave radiation, has been obtained in this laboratory and elsewhere, the effects of EMP exposure will be compared to microwave exposure effects using similar end-points. (AUTHOR ABSTRACT)

AUTHOR Cleary, S. F.
YEAR 1978
TITLE Investigation of the Biological Effects of Pulsed Electrical Fields. Annual Progress Report No. 3.
SOURCE NTIS Report No. ADA093297. 30 pp.
ABSTRACT Research conducted during the contracting period has involved a continuation of an investigation of the *in vivo* effects of exposure of Dutch rabbits to electromagnetic pulsed (EMP) fields and an *in vitro* study of the effects of transient electrical and electromagnetic fields on biomembranes. Phenomenological studies of the effects of EMP exposure of Dutch rabbits have been undertaken in an attempt to characterize the nature of the alterations induced by such fields, whereas the biomembrane studies have been directed toward a mechanistic understanding of field-induced alterations in biological model systems. (AUTHOR ABSTRACT)

AUTHOR Cleary, S. F.; Hoffman, R.; Liu, L.
YEAR 1977
TITLE Investigation of the Biological Effects of Pulsed Electrical Fields. Annual Progress Report No. 2.
SOURCE NTIS Report No.ADA091813. 74 pp.
ABSTRACT The investigation of the effects of pulsed electrical fields on mammalian erythrocytes indicates that such fields produce transient pores or channels in the cell membrane as evidenced by the release of intercellular potassium ions and hemoglobin (and perhaps other intracellullar protein molecules). The release has been found to be strongly dependent upon the duration of the electric field pulse as well as the amplitude of the electric field. Significant intracellular potassium release occurs under exposure conditions that do not result in release of protein molecules, suggesting that the size of the induced pore is dependent upon the induced field strength and the duration of the field. The mechanism of dielectric breakdown of cell membranes does not adequately account for these results. The results of studies of the relationship of field strength and pulse duration for the rupture of an artificial bilayer lipid membrane (oxidized cholesterol) indicate a dependency on the pulse duration that is consistent with the effects upon cell membrane permeability. The *in vivo* studies have involved the exposure to Dutch rabbits to repetitively pulsed electromagnetic fields in an EMP simulator. Such exposure has not been found to result in significant alterations in a number of physiological response variables including the duration of drug-induced sleeping time and serum chemistry changes, although there is some suggestion (nonstatistically significant) of a post-exposure increase in certain serum enzymes. (AUTHOR ABSTRACT)

AUTHOR Cleary, S. F.; Nickless, F.; Liu, L. M.; Hoffman, R.
YEAR 1980
TITLE Studies of Exposure of Rabbits to Electromagnetic Pulsed Fields.
SOURCE Bioelectromagnetics 1:345-352
ABSTRACT Dutch rabbits were acutely exposed to electromagnetic pulsed (EMP) fields (pulse duration 0.4 μs, field strengths of 1-2 kV/cm and pulse repetition rates in the range of 10 to 38 Hz) for periods of up to two hours. The dependent variables investigated were pentobartibal-induced sleeping time and serum chemistry (including serum triglycerides, creatine phosphokinase (CPK) isoenzymes, and sodium and potassium). Core temperature measured immediately pre-exposure and postexposure revealed no exposure-related alterations. Over the range of field strengths and pulse durations investigated no consistent, statistically significant alterations were found in the end-points investigated. (AUTHOR ABSTRACT)

AUTHOR Columbia Research Corporation
YEAR 1984 (Oct.)
TITLE Shock Hazard Analysis Report
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Vol. II, Appendix V, 37 pp.
ABSTRACT The EMPRESS II presents no shock hazard to humans on board a sailboat. Any currents induced on a sailboat mast outside the exclusion zone would be well below the perception threshold. Any magneticfield-induced currents on board the sailboat would peak too quickly to be perceived at the magnitude they occur. Electric field-coupled currents in the mast are too small to produce a noticeable current to a person making contact with it in any way. For all EMP sailboat interactions, the resultant currents through humans in contact with the mast are well below perception thresholds. This report introduces a method to determine the current through a person touching a sailboat mast exposed to EMP radiation. This problem differs from a conventional antenna problem in the following ways: sailboat mast is grounded differently; incident EMP has different frequency spectrum and larger band width than communication signals; and this is a transient (not a steady-state) situation. To reinforce the validity of this method, we will apply it to a mast and an antenna during EMP exposure and compare the result to results obtained experimentally. We also look at the possibility of using other methods to determine load currents and their applicability. The zero cross-over time of the electromagnetic spectrum produced by EMPRESS II is 10xE-7 seconds. This results in a small aperture for the collection of EMPRESS II energy by antennas and cylinders. (MODIFIED AUTHOR ABSTRACT)

AUTHOR	Gates, J. E.; Farr, P. M
YEAR	1985
TITLE	Final Report on Effects of Electromagnetic Pulse Radiation (EMP) on Avian Navigation: A Preliminary Investigation.
SOURCE	Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix P, 20 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT	Behavioral and non-behavioral effects of electromagnetic pulse (EMP) exposure on homing pigeons (*Columba livia*) were examined. An initial experiment showed no apparent physical or behavioral differences between control pigeons and those exposed to the EMP. Release experiments conducted under the sun revealed no obvious differences in initial orientation, vanishing intervals, and homing performances between experimental and control birds; however, these results should be viewed with caution due to small sample sizes. EMP exposure appeared to have no effect on the ability of pigeons to home under total overcast. Application of these findings to migratory bird species in discussed. (AUTHOR ABSTRACT)

AUTHOR	Gould, K. E.; McCoskey, R.; Tempo, K.
YEAR	1983 (Oct.)
TITLE	Environmental Impact Study of EMPRESS II
SOURCE	Environmental Impact Study of EMPRESS II, Section 4, pp. 15-17
ABSTRACT	In animal research programs, rodents, dogs, and monkeys were exposed millions of times to EMP at intensities an order of magnitude above threat level without indications of adverse effects. Similarly, physical examinations and observations of government and civilian employees at EMP facilities have not indicated any discernible effects from EMP exposure. Studies cited were conducted by Baum, Skidmore, et al. The EMPRESS Relocation Study conducted by the Naval Facilities Engineering Headquarters for Naval Surface Weapons Center at White Oak, MD showed no deleterious effects on monkeys from EMP. (Monkeys were chosen because they are similar mammals to man.) A limited series of electroencephalographic studies showed no discernible brain wave difference between EMP exposed and control monkeys. (HDL)

AUTHOR Granatstein, V. L.
YEAR 1985
TITLE Critique of Two Analyses of Shock Hazard from EMP Induction on Sailboats.
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Vol. II, Appendix W, 6 pp.
ABSTRACT The analyses of J.P. Reilly, Johns Hopkins University, and of Columbia Research Corporation of the electric shock hazard to personnel on a sailboat at the edge of the exclusion zone of EMPRESS II are compared. The analyses disagree by a factor of about 20. The threshold for painful shock lies between the values determined by Columbia Research Corporation (CRC) and J. P. Reilly. Granatstein critiques both reports and states his disagreement with both. An antenna analysis of a thin mast is made, and Granatstein suggests that the CRC report be extended to include an analysis of thin masts. In conclusion, the statement is made that there is no indication that induced voltages on sailboat masts would be large enough to cause serious harm to personnel but the possibility of a brief, painful shock cannot be ruled out. (HDL)

AUTHOR Granatstein, V. L.
YEAR 1987
TITLE Shock Hazard on Sailboats Due to EMP Testing in Chesapeake Bay.
SOURCE Presented at the Electrophysics Seminar, May 8, 1987, University of Maryland, College Park, Maryland
ABSTRACT The U.S. Navy has been conducting tests of the effects of Electromagnetic Pulse (EMP) energy on shipborne electronics, with a view to improving electronics survivability in a nuclear war environment. To date, these tests have employed the EMPRESS I EMP simulator which produces 8 kilojoule pulses; EMPRESS I is located at the Patuxent naval Air Test Center on the shore of Chesapeake Bay. The Navy is now proposing to deploy a much larger simulator, EMPRESS II, on a barge in the Bay near Bloodsworth Island; EMPRESS II would have a pulse energy of 100 kilojoules. <u>There is a raging controversy over the environmental impact of EMPRESS II</u>. This lecture will discuss in detail two of the potential environmental hazards: 1. the hazard of electric shock to pleasure-boat sailors on the Bay; and 2. the hazard of upsetting electronic control systems at the Calvert Cliffe nuclear power plant. (AUTHOR ABSTRACT)

AUTHOR Guy, A. W.
YEAR: 1975
TITLE: On EMP Safety Hazards.
SOURCE: Advisory Group for Aerospace Research and Development (AGARD) Lecture Series #78 on Radiation Hazards, Chapter 11
ABSTRACT: The only two quantitative criteria presently available for setting of electromagnetic pulse (EMP) safety standards are : (1) the ANSI C95.1 Safety Standard based on limiting thermal insult at microwave frequencies, and (2) the thresholds for the stimulation of excitable membranes by electric current. The first is not realistic for application to the EMP since the induced currents and energy deposition in exposed tissue is not based on an applied field amplitude and duration relationship, but is related only to the rise and fall time of the applied field pulse. The induced currents in the tissues of man exposed to impulsive electromagnetic (Ei) fields do not appear to be sufficient for stimulating action potentials. (AUTHOR ABSTRACT)

AUTHOR Guy, A. W.
YEAR 1975
TITLE A Note on EMP Safety Hazards.
SOURCE IEEE (Inst. Electr. Electron. Eng.) *Trans. Biomed. Eng.* 22(6): 464-467
ABSTRACT The character of transient electric fields induced in spherical homogeneous tissue models of man and animals by incident electromagnetic fields similar to that originating from lightning and EMP generators has been theoretically determined. The magnitude of the induced fields is found to be approximately proportional to the time rate of change of the incident field and independent of the pulse width. It was also found that maximum EMP induced field in spherical shaped bodies is nearly proportional to the radius of the body. Therefore, for EMP safety standards, more consideration should be given to the time rate of change of the incident field rather than to the pulse width, and when laboratory animal data are used as a guide they should be extrapolated to account for body size. (AUTHOR ABSTRACT)

AUTHOR Hamnerius, Y.; Rasmuson, A.; Rasmuson, B.

YEAR 1985

TITLE Biological Effects of High-Frequency Electromagnetic Fields on *Salmonella typhimurium* and *Drosophila melanogaster*.

SOURCE *Bioelectromagnetics* 6(4):405-414

ABSTRACT *Salmonella typhimurium* and *Drosophila melanogaster* were exposed to continuous wave (CW) 2.45-GHz electromagnetic radiation, pulsed 3.10-GHz electromagnetic radiation, CW 27.12-MHz magnetic fields, or CW 27.12-MHz electric fields (only *Drosophila*). The temperatures of the treated sample and the nonexposed control sample were kept constant. The temperature difference between exposed and control samples was less than +/- 0.3 degrees C. Ames' assays were made on bacteria that had been exposed to microwaves (SAR 60-130 W/kg) or RF fields (SAR up to 20 W/kg) when growing exponentially in nutrient broth. Survival and number of induced revertants to histidine prototrophy were determined by common plating techniques on rich and minimal agar plates. The *Drosophila* test consisted of a sensitive somatic system where the mutagenicity was measured by means of mutations in a gene controlling eye pigmentation. In none of these test systems did microwave or radiofrequency fields induce an elevated mutation frequency. However, a significantly higher concentration of cells was found in the bacterial cultures exposed to the 27-MHz magnetic field or 2.45-GHz CW and 3.10-GHz pulsed microwave radiation. (AUTHOR ABSTRACT)

AUTHOR Hellman, K. B.; Grewer, P. P.; Fowler, A. K.; Hellman, A.; Swicord, M. L.

YEAR 1985

TITLE The Effect of Electromagnetic Fields on Lymphocyte Function: Enhancement of Mitogenic Stimulation.

SOURCE The Bioelectromagnetics Society Seventh Annual Meeting 1985, San Francisco, Cal. p. 10

ABSTRACT Several studies suggest that pulsed electromagnetic fields (PEMF) influence biological processes through a cell membrane-mediated event, which affects receptor-ligand interactions and subsequent functional responses. Since membrane receptors are important in lymphocyte stimulation leading to lymphocyte proliferation in the immune response, we studied the influence of PEMF on mitogen-induced lymphocyte stimulation. The PEMF generator produced a 5.2 msec burst of bipolar pulses (200 usec positive and 20 μsec negative) repeated at 15 Hz. Splenic lymphocytes were obtained from BALB/c mice and exposed between two Helmboltz coils driven in parallel by the generator. Mitogenesis was measured by PHA-stimulated 3H-thymidine incorporation. Immediately after PHA addition, lymphocyte cultures were exposed to PEMF for different times, pulse labelled, and harvested on filters for determination of radioactivity. Enhanced mitogenic stimulation was observed after 24 and 48 hours of PEMF exposure. Although the extent of stimulation varied between experiments, increased thymidine incorporation was consistently observed in mitogen-treated cultures. These data indicate that PEMF affect PHA-induced lymphocyte stimulation either through a direct effect on PHA binding to the membrane receptor or indirectly at a subsequent step in the activation process, thus providing a model system for identifying sites and possible mechanisms of PEMF on cell function. (AUTHOR ABSTRACT)

AUTHOR Hirsch, F. G.; Bruner, A.
YEAR 1972
TITLE Absence of Electromagnetic Pulse Effects on Monkeys and Dogs.
SOURCE *J. Occup. Med.* 14(5):380-386
ABSTRACT This paper reports the results of several experiments involving different species of animals exposed to EMP's. Seven albino, female rats were subjected to three pulses of 600 kV/m, 5-7 minutes apart. The rats were evaluated for any change in their performance in a maze. Two monkeys were also exposed. One monkey received eight pulses of 300-600 kV/m at about 10 minute intervals; he was observed for changes in his response to handlers. The second monkey was trained in a shock avoidance task, then he received 10 pulses: 5 at 300 kV/m, 3 at 45 kV/m and two at 600 kV/m. Four untrained dogs were studied for possible hematological and blood chemistry changes due to EMP exposure. The dogs received 4 pulses of 330 kV/m at 10 minute intervals. SMA automatic analyses were performed on the dog's blood at 1 hour and 24 hours following EMP exposure. The rats experienced a temporary (<1 hour) decrement in performance on the maze. No behavioral changes were observed with either of the monkeys, or the dogs following EMP exposure. The SMA-12 and hematological tests revealed no changes in the blood chemistry of the dogs. [These studies appear to have been a prelude to later testing for chronic effects of EMP].*

AUTHOR Hirsch, F. G.; McGiboney, D. R.; Harnish, T. D.
YEAR 1968
TITLE The Psychologic Consequences of Exposure to High-Density Pulsed Electromagnetic Energy.
SOURCE *Int. J. Biometeor.* 12(3):263-270
ABSTRACT Five albino female rats which had been trained to run a maze were exposed to 3 nanosecond pulses of electromagnetic energy which had a density of 600,000 $(v/m)^2$. A disturbance of the ability of the animals to perform this recently learned task was observed. The effect was found to be reversible within a period of 30 min. Possible mechanisms by which the decision making strategy of the animals was temporarily disrupted are considered. The parallelism between the conditions of this experiment and those attending the exposure of animals to lightning bolts during electrical storms is pointed out. (AUTHOR ABSTRACT)

AUTHOR Hocutt, C. H.; Nemeth, D. J.
YEAR 1985
TITLE Final Report. Acute Effects of Electromagnetic Pulses (EMP) on Fish.
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix N, 23 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT From studies conducted on a representative group of Chesapeake Bay fishes, it appears that acute mortality of EMP is negligible under the experimental conditions described herein. Statistical analyses indicate no significant difference in mortality between experimental (2.0% ambient; 0.6% $20^{o}/oo$) and control fishes (1.6% ambient; 1.4% $20^{o}/oo$) tested in the laboratory or *in situ* at EMPRESS I. It is considered that field conditions (weather, handling, etc.) place far greater stress on test animals than do laboratory conditions. Furthermore, normal electric field strengths are approximately 12 times higher in the laboratory than at EMPRESS I. This may be sufficient justification to primarily conduct laboratory tests in the future as opposed to field studies. (MODIFIED AUTHOR ABSTRACT)

AUTHOR Hulsheger, H.; Niemann, E. G.
YEAR 1980
TITLE Lethal Effects of High-Voltage Pulses on *E. Coli* K12.
SOURCE Radiat. Environ. Biophys. 18(4):281-288
ABSTRACT The lethal effects of high-voltage capacitor discharges in suspensions of *E. coli* K12 with varying electrolytes have been examined. A reduction of more than 99.9% of living cells, dependent on the applied voltage could be proved. The bactericidal action is assumed to be due to direct effects of high electric fields. Electrolytically produced chlorine was shown to act as an additional toxic agent, when chloride is present in the treated medium. The relative survival rate of bacteria has been found to depend also on the concentration of cells during pulse treatment. (AUTHOR ABSTRACT)

AUTHOR	International Nonionizing Radiation Committee of the International Radiation Protection Agency.
YEAR	1984
TITLE	Interim Guidelines on Limits of Exposure to Radiofrequency Electromagnetic Fields in the Frequency Range from 100 kHz to 300 GHz.
SOURCE	*Health Physics* 46(4):975-984.
ABSTRACT	This document provides guidance on limits of exposure to radiation and fields in the entire electromagnetic frequency range of 100 kHz to 300 GHz, including that range referred to as microwave radiation, 300 MHz to 300 GHz. These guidelines are based on current knowledge of biological effects and assessments of health hazards. They apply to industrial exposures and that of the general public.*

AUTHOR	Johnson, P. G.
YEAR	1986
TITLE	EMPRESS Simulators and Birds (Letter).
SOURCE	Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Appendix S, 3 pp.
ABSTRACT	Several EMP simulators are at Kirtland AFB, NM, some of them operational since 1964. Simulators produce field intensities that can be greater than 250 kV/m in certain locations within the structures. Many birds have been observed resting on the simulator structures when the pulser has discharged into the structure, but no deleterious effects have been witnessed on these birds. Typical observation is a startle reaction created by the pulser's firing pop. Some birds fly off the structure because of the startle, but it is equally probable that some birds remain on the structure for repeated firings. No electric shock effect has been observed. There is no potential difference found over the bird's body, which is the same principle allowing personnel to work on high tension commercial power lines. At some EMP generators at Kirtland AFB which have been operated on a daily basis for months, bird nests with young (owl) have been established in and around simulators with no harmful effects on young. Quail also nest and raise young in the immediate vicinity. A few miles to the west is a major migratory route for geese, ducks, and cranes. In summary no harmful effect from EMP have been observed on the area wildlife.(HDL)

AUTHOR Kenyon, C. S.
YEAR 1987
TITLE Report on V. L. Granatstein's Talk, "Shock Hazard on Sailboats Due to EMP Testing in Chesapeake Bay."
SOURCE Electromagnetic Effects Survivability Laboratory, Harry Diamond Laboratories, Adelphi, Maryland. 2 pp.
ABSTRACT The author presents calculations and conclusions arrived at by Granatstein and presented in a lecture at the University of Maryland. Granatstein's worst-case calculations of potential shock hazards from EMPRESS I (6 A) differed considerably from those of the Naval Surface Weapons Center (0.89A), and he stated that his calculations were much more in agreement with the Navy's measurements than were the Navy's. Another concern addressed was the potential for electrical disruption of electronic controls at the Calvert Cliffs nuclear power station. The Navy reported no observed effects from operation of EMPRESS I and no anticipated effects from EMPRESS II due to the three-times greater distance to the power plant. Granatstein argued that, since the distances involved with EMPRESS II are over water instead of land in the case of EMPRESS I, his calculations indicate that the fields resulting from EMPRESS II could exceed by 10 to 30 times those from EMPRESS I.*

AUTHOR Lin, J. C.; Wu, C. L.; Lam, C. K.
YEAR 1975
TITLE Transmission of Electromagnetic Pulse into the Head.
SOURCE *Proc. IEEE* 63(12):1726-1727
ABSTRACT Characteristics of electromagnetic pulse transmission in homogeneous spherical models of human and animal heads are studied as a function of time and position. The incident pulse waveform is described by a triple exponential waveform which exhibits close agreement with measured pulse shapes. The transmitted pulse is shown to be proportional to the time rate of change of the incident pulse, with peak occurring at the leading surface of the spheres. (AUTHOR ABSTRACT)

AUTHOR Lyle, D. B.; Kamin, G. W.; Ayotte, R. D.; Adey, W. R.
YEAR 1985
TITLE T-Cell Growth Factor Production and 3H-Thymidine Incorporation by the myeloid leukemia Cells Ml and U-937 in the Presence of 12-O-Tetradecanoylphorbol-13-Acetate (TPA) are Unaffected by a 60Hz Pulsed 20 Gauss Magnetic Field.
SOURCE The Bioelectromagnetics Society Seventh Annual Meeting 1985, San Francisco, CA. p. 55
ABSTRACT To evaluate the potential of a magnetic field to act as a primary or secondary tumor promoter, cells treated with the well-characterized tumor promoter TPA were cultured in the presence of a 60Hz pulsed 20 gauss magnetic field which was generated by a Helmholtz coil pair. (The pulse configuration consisted of a 300 microsecond ramp to a peak of 20 gauss with a rapid falling phase of 20 microseconds.) Conditions were chosen such that an optimal concentration of TPA (1.0 ng/ml) would elicit a 50% or greater change from responses seen in control cultures, with lesser concentrations of TPA producing no or little change. The endpoint evaluated was the uptake of 3H-thymidine by the myeloid leukemia cell lines Ml (of muric origin) and U-937 (of human origin). Also assayed was the production of TCGF by concanavalin A-stimulated rat spleen cells in the presence or absence of the magnetic field. None of the parameters assayed were altered by the presence of the field. These results suggest that these magnetic fields do not act synergistically with suboptimal doses of TPA as secondary tumor promoters. (AUTHOR ABSTRACT)

AUTHOR Martin, J. A.
YEAR 1970
TITLE Biological Effects of Fields of the Siege Array.
SOURCE NTIS Report No. AD904748. 18 pp. Air Force Weapons Laboratory, Kirtland Air Force Base, N.M.
ABSTRACT The purpose of this report is to evaluate the effects of large pulse fields, such as will be produced by the Siege 1.2 and Siege II generators on personnel in the vicinity of the Siege array. A survey of available literature on biological effects of electromagnetic radiation has been made and is summarized. In addition, the voltages and currents induced in an average-size man are computed and presented. (AUTHOR ABSTRACT)

AUTHOR Mattsson, J. L.; Oliva, S. A.
YEAR 1976
TITLE Effect of Electromagnetic Pulse on Avoidance Behavior and Electroencephalogram of a Rhesus Monkey.
SOURCE NTIS Report No. ADA033732; Armed Forces Radiobiology Research Institute Report No. AFRRI-SR76-29, 18 pp.
ABSTRACT Upon detonation, nuclear weapons create an electromagnetic pulse (EMP) as well as blast, thermal, and radiation energy. The EMP is known to have a deleterious effect on some types of electronic equipment, but it is unknown whether or not EMP has an effect on personnel. Most animal research data are negative, but research was performed on untrained animals. The objective of this experiment was to evaluate the effects of repeated, high-density EMP on electroencephalogram and performance of a highly trained rhesus monkey. A 12 kg rhesus monkey was exposed to EMP at 266 kV/m, 5 pps, for 1 hour (18,700 pulses). The effects of EMP on Sidman avoidance behavior and on postexposure EEG were evaluated, and no significant changes were detected. An analysis of EMP showed it contained frequency components extending from 0 Hz to 10^9 Hz. However, the pulse configuration was such that its power was mainly confined to the longer wavelengths (30 MHz). The lack of biologic effect was attributed to the fact that the wavelengths were long, relative to the size of the monkey, and little energy deposition was likely to occur. In addition, electric field was evenly distributed across all lower frequencies so that only a very small electric field component existed at any specific low frequency. (HDL)

AUTHOR Milroy, W. C.; O'Grady, T. C.; Prince, E. T.
YEAR 1974
TITLE Electromagnetic Pulse Radiation: A Potential Biological Hazard?
SOURCE *Biol. Eff. Electromagnetic Radiat.* 1(1):31
ABSTRACT Concern has arisen over the bioeffects of electromagnetic pulse radiation (EMP) due to the very high field densities involved, i.e., hundreds of thousands of volts/meter. No significant effects were observed in an Air Force pilot study involving several dogs, a monkey, and maze-trained mice. A Russian study of EMP effects on humans showed an intensity-time relationship on the appearance of phosphenes in the visual field. In a study being conducted by the Armed Forces Radiobiological Research Institute, a large rat population is continuously irradiated by a pulsed field of approximately 500 kV. The population is being monitored for a variety of physiological parameters; no significant results have been obtained thus far. In addition to these experimental studies, reviews of health records of several hundred workers at EMP generator facilities have shown no significant bioeffects. (AUTHOR ABSTRACT)

AUTHOR Milroy, W. C.; O'Grady, T. C.; Prince, E. T.
YEAR 1974
TITLE Electromagnetic Pulse Radiation: A Potential Biological Hazard?
SOURCE *J. Microwave Power* 9(3):213-218
ABSTRACT Concern is arising as to the potential biological effects of Electromagnetic Pulse Radiation. Much of this concern is due to a lack of sufficient data rather than to any effects actually being observed. Available data are reviewed and ongoing research reported. (AUTHOR ABSTRACT)

AUTHOR Pazderova-Vejlupkova, J.; Josifko, M.
YEAR 1979
TITLE Changes in the Blood Count of Growing Rats Irradiated With a Microwave Pulse Field.
SOURCE *Arch. Environ. Health* 34(1):44-50
ABSTRACT A group of 20 male rats of mean initial body weight of 65.53 g were irradiated for 7 wk (5 days per wk, 4 hr per day) with an electromagnetic pulse field of the following parameters: working frequency 2,736.5 MHz; repeated frequency 395 Hz; pulse width 2.6 μ; vertical polarization; mean power density 24.4 mW/cm^2; accuracy of measuring +/- 6%. The rectal temperature of experimental animals increased during irradiation by a maximum of 0.5 degrees C. Blood was taken before irradiation, at the end of the 1st, 3rd, 5th, and 7th wk of irradiation, and at the end of the 1st, 2nd, 6th, and 10th wk after irradiation was completed. The parameters under study included the hematocrit value; number of leukocyte differential count in both absolute and relative proportions; activity of alkaline phosphatase in neutrophil leukocytes; and body weight increase. The results were compared with parallel data obtained from a control group of 20 animals and evaluated by Student's t-test at a significance level of 1%. In the second half of the irradiation period the experimental animals exhibited significantly lower mean hematocrit values, lower numbers of leukocytes, and lower absolute numbers of lymphocytes. These changes disappeared gradually within 10 wk after completed irradiation. Activity of alkaline phosphatase in neutrophil leukocytes was significantly increased in the 1st wk of irradiation and dropped transiently after the irradiation. In the post-irradiation interval experimental animals displayed significant decline in rate of body weight increase. The level of the other examined parameters did not differ from the controls. (AUTHOR ABSTRACT)

AUTHOR Pierluissi, J. H.
YEAR 1975
TITLE Effects of Electromagnetic Fields Below 30 MHz on Animal Biology.
SOURCE NTIS Report No. UCRL-51880. 14 pp.
ABSTRACT The literature describing the effects of radio frequency (rf) electromagnetic fields on animal biology is reviewed. The study is limited to frequencies below 30 MHz. Also, a table is provided which summarizes organic (nonthermal) effects on various biological organisms as found by 30 researchers. (AUTHOR ABSTRACT)

AUTHOR Pomponi, S. A.
YEAR 1986
TITLE EMPRESS I. The Effect of High Energy Electromagnetic Pulses on Aquatic Biota. Revised Final Report: Cell Physiology Studies.
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix T, 38 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT The objective of the cell physiology studies was to determine the effects of EMP's on blood or hemolymph cells of indigenous Chesapeake Bay species. These cell types are known to be responsive to physical and chemical perturbations and are, therefore, useful indicators of environmental stress. Cell volume and DNA fluorescence were measured by flow cytometric analysis of control and laboratory-pulsed samples of five species: the American oyster (*Crassostrea virginica*), blue crab (*Callinectes sapidus*), mummichog (*Fundulus heteroclitus*), sheepshead minnow (*Cyprinodon variegatus*), and striped bass (*Morone Saxatilis*). The data presented demonstrate that there are some differences between the control and pulsed species. Results were inconsistent, however, and varied both among species as well as within the same species. Possible causes of differences and variations are discussed. (MODIFIED AUTHOR ABSTRACT)

AUTHOR Sandler, S. S.; Smith, G. S.; Albert, E. N.
YEAR 1975
TITLE Electromagnetic field effects in nerve tissue.
SOURCE *Aviat. Space Environ. Med.* 46(11):1414-1417
ABSTRACT In the present work, an attempt has been made to produce structural alterations in tissue from the nervous system of bullfrogs by means of a high-intensity electric field. The electric field used to expose the tissue was composed of a train of high-intensity, short-duration pulses. These pulses provide a high electric-field intensity in the tissue, yet a low enough absorbed-energy density to cause negligible thermal heating. Exposed and control tissue prepared for light microscope investigation was stained with thionin and hematoxylin and eosin stains. No gross histological alterations of the large motor neurons of the exposed tissue were found when compared with the control tissue. (AUTHOR ABSTRACT)

AUTHOR Science Applications International Corporation
YEAR 1987
TITLE Preliminary Draft Environmental Assessment for VEMPS II.
SOURCE Prepared for the Electromagnetic Effects Survivability Laboratory, Harry Diamond Laboratories, Woodbridge, Virginia, 64 pp.
ABSTRACT This document reports potential effects of the construction and operation of the vertically polarized electromagnetic pulse simulator (VEMPS II) at the Harry Diamond Laboratories in Woodbridge, Virginia. This facility will radiate high-frequency radio waves more strongly than other EMP simulators. EMP effects on electronics and potential shock hazards and other effects on humans and other biological systems were studied. The major off-base electronic effect of concern was potential interference with cardiac pacemakers; data indicated that such effects would not occur at the low EMP levels produced at off-base sites. Communications and power equipment were not expected to be affected. Data indicated that any potential shock hazard off-base was very unlikely. Medical surveys of EMP simulator personnel, animal studies, and a literature review all supported the conclusion that operation of VEMPS II would not affect humans or other biological systems.*

AUTHOR Skidmore, W. D.; Baum, S. J.

SOURCE 1974

TITLE Biological Effects in Rodents Exposed to 10^8 Pulses of Electromagnetic Radiation.

SOURCE *Health Phys.* 26(5):391-398; NTIS Report No. ADA762038 (1973), 23 pp.

ABSTRACT Rodents were exposed to electromagnetic pulse (EMP) radiation to test the hypothesis that rapid changes in electric and magnetic fields would induce injuries in biological systems with high cell turnover rates. The AFRRI EMP generator provided five pulses per second with a peak electric field intensity of 447 kV/m with a 5 nsec rise time and 550 nsec 1/e fall time. Exposures, totaling 10xE8 pulses, were continuous except for approximately 2 hr, 5 days per week for biological sampling and animal care during 38 weeks. Biological assays were periodically conducted in exposed and nonexposed animals at appropriate intervals. It was observed that the reticulocyte count in exposed rats was nearly always greater than in nonexposed rats. However, there were no concomitant differences in peripheral erythrocyte counts between the two groups, nor did radioactive iron incorporation indicate increased cellular production in the irradiated group. Platelet counts in exposed rats were decreased about 10% below those in the nonexposed group most of the time. Levels or relative counts of circulating leukocytes did not differ between the two groups. Bone marrow cellularity was not different between the two groups. Analysis of chromosomes from bone marrow cells showed no detectable increases of aberrations in EMP exposed rats. Routine chemical analysis of blood demonstrated similar values in the two groups. Histological studies indicated no effect of EMP. Observations of fetuses from pregnant rats showed no abnormalities. No incidence of mammary tumors was observed in the female Sprague-Dawley rats. In leukemia-prone AKR/J male mice, leukemia did not occur earlier in EMP exposed animals, nor was the fraction of leukemic mice greater in this group when compared with the nonirradiated control mice. The present experiment utilizing the above-described physical parameters represented a condition exceeding by several orders of magnitude that normally encountered by humans who operate EMP facilities. Exposures of rodents under these conditions indicated no apparent acute injuries. (AUTHOR ABSTRACT)

AUTHOR Skidmore, W. D.; Baum, S. J.; Wyant, D. E.
YEAR 1974
TITLE Biological Effects of Electromagnetic Pulses.
SOURCE NTIS Report No. ADA009327, pp. 3-5. Annual Research Report: July 1973-June 9174, Armed Forces Radiobiology Research Institute.
ABSTRACT In order to determine biological effects of chronic exposure to pulsed electromagnetic radiation, male and female rats were exposed to 2.4 x 10xE8 pulses from the AFRRI EMP simulator for 90 weeks. After 38 weeks' exposure, the reticulocyte count appeared to be elevated, while the platelet count decreased, although both remained within acceptable levels. After two years' exposure, however, these apparent differences disappeared, and there was no evidence that hematological parameters were affected by EMP exposure. From these results, plus fertility tests (including examination of progeny) and histological studies, the authors conclude that continuous exposure to EMP radiation (five pulses per second and a peak field intensity of 447 kV/m) produced no adverse effects in rats.*

AUTHOR Skidmore, W. D.; Brunhart, G.
YEAR 1974
TITLE Biological Effects of Pulsed Electromagnetic Fields.
SOURCE *Biol. Eff. Electromagnetic Radiat.* 1(2):55
ABSTRACT The objective of this research is to determine biological hazards associated with long term exposure to electromagnetic pulsed fields (EMP). Sixty male leukemia-prone mice (AKR-J), 20 mammary tumor-prone female Sprague-Dawley rats and 150 male rats to be serially sacrificed for bioassay data will be exposed continuously (23 hr/day) in an EMP field for approx 1 yr. An equal number of animals will serve as controls. The exposure will consist of 1 pulse/second with a peak field intensity up to 500 kV/m and a mixed frequency component up to 100 MHz. Data will be evaluated to determine if any abnormal biological effects such as an increased incidence and rate of neoplasms, changes in hematological parameters, increased chromosomal aberrations, etc., occurred during the exposure period. Results will be applied to potential occupational hazards associated with long term exposures to electromagnetic pulsed fields. (AUTHOR ABSTRACT)

AUTHOR Stender, J. H.
YEAR 1974
TITLE Exposure to Electromagnetic Pulses.
SOURCE *Fed. Regist.* 39(39):7499
ABSTRACT The Occupational Safety and Health Administration (OSHA) published this request for information to solicit comments on the Boeing Company's request to establish a standard on exposure to electromagnetic pulses (EMP's). Included in the notice was a formula for determining maximum permissible exposure to EMP's taken from a 1972 Air Force document, "Provisional Safety Criteria for Use in Electromagnetic Pulsers." Comments were to have been received by OSHA before March 28, 1974.*

AUTHOR Stender, J. H
YEAR 1975
TITLE Exposure to Electromagnetic Pulses.
SOURCE *Fed. Regist.* 40(111):24579-24580
ABSTRACT This notice was published as a result of the comments received following publication of the Boeing Company's request for an exposure standard for electromagnetic pulses (EMP's). Of 31 submissions in response to the previous notice, the majority indicated that the need for such a standard had not been established, and that appropriate scientific information was not available upon which to base such a standard. OSHA therefore determined that a such a standard should not be issued.*

AUTHOR Swanson, D. R.
YEAR 1987
TITLE Request for Review of Army EMP Personnel Exposure Standard.
SOURCE Personal Communication to the Commander, U.S. Army Materiel Command, Alexandria, Virginia. Available EA-Bio-13 File, Harry Diamond Laboratories, Woodbridge, Virginia
ABSTRACT A question arose as to whether the Army standard of 100 kV/m for personnel exposure to electromagnetic pulse is necessary. Swanson states that "The question of DoD STD 2169 simulator safety should have been addressed in the Environmental Assessment." Research has not proven any adverse biological effects of EMP exposure. In the author's opinion, there is not enough information available to determine whether the current standard should be changed.*

AUTHOR Takahashi, K.; Kaneko, I.; Date, M,.; Fukada, E.
TITLE Effect of Pulsing Electromagnetic Fields on DNA Synthesis in Mammalian Cells in Culture.
YEAR 1986
SOURCE *Experientia* 42(2):185-186
ABSTRACT DNA synthesis in Chinese hamster V79 cells was significantly enhanced when they were exposed to weak, pulsing electromagnetic fields generated by specific combinations of the pulse width (25 microseconds), frequency (10, 100 Hz) and magnetic intensity (2 X 10xE-5 T, 8 X 10xE-5 T). Conversely the DNA synthesis of cells in the fields at 4 X 10xE-4 T was repressed to 80% of that in controls not exposed to the fields. (AUTHOR ABSTRACT)

AUTHOR Tempo, K.
YEAR 1986
TITLE EMPRESS II EMP Simulator Effects on Commercial Marine Electronics
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Vol. II, Appendix BB, 50 pp.
ABSTRACT A program was conducted to examine and test a representative sample of commercial marine electronic communications and navigation equipment when exposed to an electromagnetic pulse similar to that which will be produced by the EMPRESS II with the objective of gaining some empirical data to support (or refute) the belief that this simulator will not have an adverse affect on civilian electronics operating outside the 2 nautical miles EMPRESS II exclusion area. The program was based on the careful selection of representative products that incorporate state-of-the-art electronic technologies. Functional testing of the equipment was accomplished with the equipment installed in the 39' sailing yacht SALISHAN while being subjected to a variety of field strength pulses between 380 V/m and 8.4 kV/m. Sensitivity measurements were also made on the equipment to determine if exposure to multiple pulses could result in long-term sensitivity changes. The equipment being tested (two VHF/FM transceivers, a LORAN-C, and an RDF) experienced no permanent damage or loss of sensitivity. No upsets or malfunctions of the equipment being tested were observed at field strengths up to 3.7 kV/m, equivalent to a distance more than 1.25 nmi inside the EMPRESS II exclusion area. Although not a part of the experiment, an integrated digital sailing instrumentation package on board the test vessel was upset regularly at the 1.35 kV/m level and down to less than 380 V/m. This equipment was presumably damaged at the higher field strength levels experienced within 3/4 nmi of the EMPRESS II. It was concluded that commercial marine electronics equipment can be operated at the EMPRESS II exclusion area radius without risk of damage. Upsets of digital equipment may occur and any vessels operating in the vicinity of the EMPRESS II exclusion area should be warned to be alert for upset and erroneous readings. (AUTHOR ABSTRACT)

AUTHOR Thomas, J. R.; Schrot, J.; Banvard, R. A.

YEAR 1982

TITLE Comparative Effects of Pulsed and Continuous-Wave 2.8-GHz Microwaves on Temporally Defined Behavior.

SOURCE *Bioelectromagnetics* 3(2):227-235. NTIS Report No. ADA131171; NMRI 82-91, 9 pp. Naval Medical Research Institute, Bethesda, Maryland.

ABSTRACT The effects of pulsed- (PW) and continuous-wave (CW) 2.8-GHz microwaves were compared on the performance of rodents maintained by a temporally defined schedule of positive reinforcement. The schedule involved food-pellet reinforcement of behavior according to a differential-reinforcement-of-low-rate (DRL) contingency. The rats were independently exposed to PW and to CW fields at power densities ranging from 1 to 15 mW/cm^2. Alterations of normal performance were more pronounced after a 30-minute exposure to the PW field than to the CW field. The rate of emission of appropriately timed responses declined after exposure to PW at 10 and 15 mW/cm^2, whereas exposure at the same power levels to the CW field did not consistently affect the rate of responding. Change in performance associated with microwave exposure was not necessarily related to a general decline in responding; in some instances, increases in overall rates of responding were observed. (AUTHOR ABSTRACT)

AUTHOR	Tsai, C.; Millsaps, H. S.
YEAR	1985
TITLE	Final Report. The Effect of High Energy Electromagnetic Pulse on Plankton.
SOURCE	Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix L, 87 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT	Laboratory and field studies were conducted to determine the effects of EMP on the primary productivity and biomass of the phytoplankton community, (including the algae *Thalassiosire pseudonana* and *Isochrysis galbana*) and on the mortality, growth, and reproduction of zooplankton (the copepods *Eurytemora affinis* and *Acartia tonsa*). An EMP simulator generating EMP at an intensity equivalent to that at a site 100 m from the EMPRESS II pulser was used in the laboratory study. The EMP doses were 0 (control), 1, 5, 10, 50, and 100 pulses. Three field test stations were situated 144.2 m, 216.7 m, and 303.3 meters, respectively, from the EMPRESS I pulser at Point Patience on the Patuxent River. The control station was at the Chesapeake Biological Laboratory pier, 1.7 nautical miles from EMPRESS I. There were no differences between test populations and controls in total carbon uptake rates of the phytoplankton community; growth rates of the algae; and the mortality, growth rates, fecundity, and reproductive rates of the copepods. There was no significant correlation between these biological parameters and the EMP doses in the laboratory study nor between the parameters and the distances of the test stations from the EMP source in the field study. The lack of effects was attributed to the combination of extremely short pulse duration, extremely low pulse frequency, and the very small size of the plankton.*

AUTHOR	United States Navy, Atlantic Division, Naval Facilities Engineering Command
YEAR	1986
TITLE	Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean.
SOURCE	U.S. Navy, Atlantic Division, Naval Facilities Engineering Command, Draft Report Volumes I and II, Norfolk, Virginia.
ABSTRACT	This two-volume report is a description of the potential environmental impacts anticipated with the operation of the Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II).. This device is barge-mounted and towable; it will operate in the Chesapeake Bay and the Atlantic Ocean. Wildlife as well as human impacts are considered.*

AUTHOR Van Heukelem, W. F.
YEAR 1985
TITLE Effects of Exposure to Electromagnetic Pulses on Selected Estuarine Invertebrates. Final Report.
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix M, 12 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT Three invertebrate species important to the Chesapeake Bay were selected for study. Adult and larval life stages of blue crabs, oysters, and grass shrimp were used in tests; additionally, juvenile stages of blue crabs and oysters were exposed to EMPs. While most exposures were accomplished using a laboratory-scale EMP generator provided by the Navy, some organisms in cages were exposed to EMPs generated by the EMPRESS I pulser at Point Patience on the Patuxent River. In most cases, mortality of control animals exceeded that of animals exposed to EMPs, suggesting that all observed mortality was due to factors other than exposure to EMPs. Statistical tests indicated no significant differences in mortality between experimental and control animals. The observed mortality was attributed to handling and overcrowding in the case of the blue crabs and to handling in the case of the larvae of all species tested.*

AUTHOR Wik, M.
YEAR 1975
TITLE EMP Effects on Mankind.
SOURCE NTIS Report No. AWRE-Trans-67, 12 pp.; (translation by F. E. Wallwork and D. R. Quested of Research Institute of National Defence, Stockholm, Sweden Report No. FOA--4-A-4500-29)
ABSTRACT The effects of electromagnetic pulses (EMP) on humans are very much a problem of secondary importance in the context of nuclear explosions. This report is intended to present a basis for the evaluation of EMP effects on man in those cases where such effects can, if at all, be contemplated. The report deals with conceivable causes of the effects, electric shock, and protection against the effects of EMP on man. (AUTHOR ABSTRACT)

AUTHOR Wiley, M. L.
YEAR 1985
TITLE The Effect of High Energy Electromagnetic Pulses on the Clearnose Skate, *Raja eglanteria*. EMPRESS I - Final Report.
SOURCE Supplemental Draft Environmental Impact Statement for the Proposed Operation of the Navy Electromagnetic Pulse Radiation Environment Simulator for Ships (EMPRESS II) in the Chesapeake Bay and Atlantic Ocean, Volume II, Appendix O, 10 pp. Norfolk VA: U. S. Navy, 1986.
ABSTRACT This report describes laboratory experiments that were conducted to determine if electromagnetic pulses (EMP) from the EMPRESS II pulser might have deleterious effects on the behavior of elasmobranch fishes (sharks, skates, and rays). Of particular interest was whether the EMP could be detected by means of the Ampullae of Lorenzini, the sensory structures that elasmobranchs use to detect the low-level electrical fields produced by living prey organisms, and whether EMP might damage the functioning of the ampullary system. Feeding experiments using the knock and EMP as conditioning stimuli were not conclusive. The skates appeared to respond to the knock but did not score better at the end of the training period than at the beginning. The skates receiving EMP appeared to improve their response time, but the differences were not statistically significant. The feeding experiments with prey concealed in open and agar-plugged containers indicated that exposure to EMP may affect the Ampulla of Lorenzini system to some extent. The authors emphasized that the test animals were repeatedly exposed to near-maximum intensity of EMP and received a dosage of EMP not likely to be experienced by free-living organisms.*

APPENDIX B

EMP SIMULATORS AND PUBLIC SAFETY: AN ANALYSIS

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EMP SIMULATORS AND PUBLIC SAFETY: AN ANALYSIS (SUMMARY)

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Fffects produced by EMP simulators and associated electrical transients are analyzed for their potential danger to humans. Comparison is made with standards established for radio frequency electromagnetic fields.

Concerns about the biological effects of EMP and its associated electrical transients have led to many studies.[1,2] At present, these studies indicate that there is no hazard to the public. This paper analyzes the electromagnetic effects produced by EMP simulators to the public with reference to existing federal standards on radio frequency electromagnetic (RFEM) fields.[3] Typical EMP parameters (E_H = 50 kV/m, E_V = 15 kV/m, $\alpha = 4 \times 10^6$/s, $\beta = 4.76 \times 10^8$/s) are used throughout this paper.

Energy from a Single EMP. The energy density from a single EMP in free space is

$$W_o = \frac{E_o^2}{\eta} \int_0^\infty \left(e^{-\alpha t} - e^{-\beta t} \right)^2 dt = \frac{E_H^2 + E_V^2}{\eta} \frac{(\beta - \alpha)^2}{2\alpha\beta(\alpha+\beta)} \approx 0.9 \text{ J/m}^2 , \qquad (1)$$

where η is the impedance of free space. Since the cross-sectional area of a human is about one square meter, direct coupling of the EMP to humans is not a concern. The case in which someone is attached to some big energy collector, such as a metallic tower or a transmission line, is of concern. Studies of shocks in connection with vertical towers have been reported.[4] The transmission line description follows the literature.[5] To keep the mathematics manageable, assume that the transmission line is ideal and

impedance matched with $Z(\ell) = R_b \approx 350\Omega$ (impedance of the human body).[4] The EMP induced voltage across the body is[5]

$$V(j\omega) = c\ D\ G(1 - e^{-j\omega t_o})\ (1 - e^{-j\omega t_\ell}) \quad , \tag{2}$$

$$D = \frac{E_H \sin\phi + E_V \sin\psi \cos\phi}{1 - \cos\phi \cos\psi} \quad , \quad G = \frac{1}{j\omega}\left(\frac{1}{\alpha + j\omega} - \frac{1}{\beta + j\omega}\right) \quad , \tag{3}$$

$$t_o = 2\ h \sin\psi / c, \ t_\ell = (1 - \cos\phi \cos\psi)\ \ell / c \quad . \tag{4}$$

The energy absorbed by the human body is

$$W = \frac{1}{\pi R_b} \int_o^\infty |V(j\omega)|^2 d\omega = P_o\ T_o \quad , \tag{5}$$

$$P_o = \frac{2}{R_b}\left[\frac{cD(\beta - \alpha)}{\alpha\beta}\right]^2 \quad , \quad T_o = t_1 - \frac{1}{2}\left(\frac{1}{(\beta^2 - \alpha^2)}\right)\left(\frac{\beta^2 \zeta_1}{\alpha} - \frac{\alpha^2 \zeta_2}{\beta}\right) \quad , \tag{6}$$

$$\zeta_1 = 2(1 - e^{-\alpha t_1} - e^{-\alpha t_2}) + e^{-\alpha(t_2 - t_1)} + e^{-\alpha(t_1 + t_2)} \quad , \tag{7}$$

$$\zeta_2 = 2(1 - e^{-\beta t_1} - e^{-\beta t_2}) + e^{-\beta(t_2 - t_1)} + e^{-\beta(t_1 + t_2)} \quad , \tag{8}$$

$$t_1 = \mathrm{MIN}\ (t_o, t_\ell) \quad , \quad t_2 = \mathrm{MAX}\ (t_o, t_\ell) \quad . \tag{9}$$

The derivation of this result is a tedious but elementary task. Figure 1a shows the energy absorbed by the human body in contact with typical commercial transmission lines. The amount of energy is substantial and may be hazardous. However, commercial transmission lines are typically handled by professionals; therefore, this case is not of public concern. Figure 1b shows the amount of energy absorbed by the human body when it is in contact with a line at a height $h = 2$ m (about the reach of an adult person). The length $\ell = 15$ m depicts a typical metallic clothes line. As seen from Fig. 1b the energies absorbed by persons are relatively small and harmless.

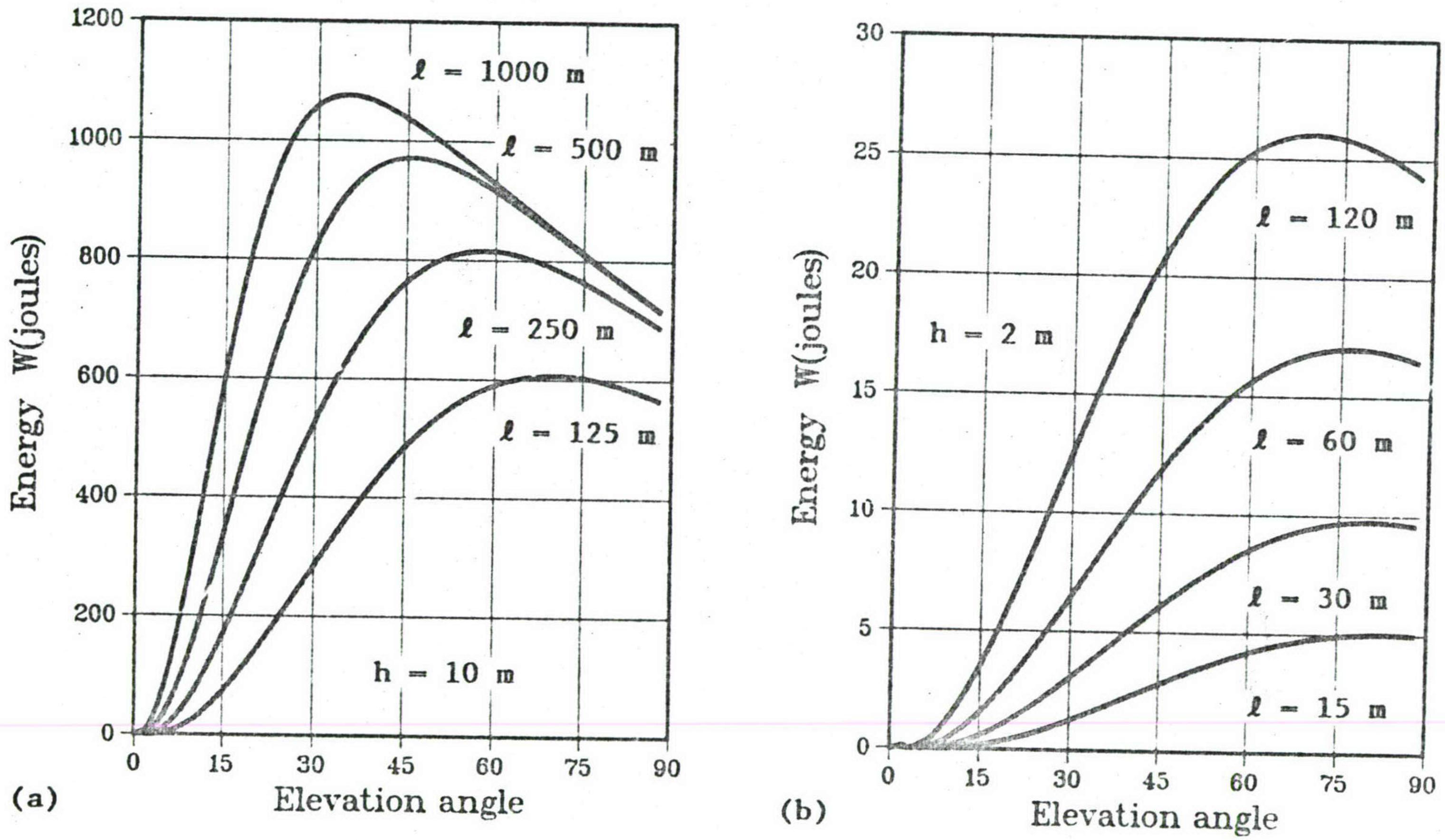

Fig. 1. Energy vs elevation angle delivered by a single EMP to a person attached to a transmission line

Energy from Repetitive EMPs. To determine the EMP hazard by the RFEM fields standard, assume that the simulator is fired repeatedly every T seconds [repetition rate $r = 1/T$ (EMPs/s)]. For $e^{-\alpha T} \approx e^{-\beta T} = 0$, the radiated power density at a distance d from the simulator is

$$P = \frac{E^2}{\eta} \frac{(\beta - \alpha)^2}{2\,\alpha\beta(\alpha + \beta)}\, r \quad . \tag{10}$$

E is the far-electric field density of the simulator. Figure 2 shows the required repetition rate, r, of the simulator in order to produce $1 \mathrm{mW/cm^2}$, stated in the standard, $E = 25 \times 10^5/d$ V/m (50 kV/m at d = 50 m). The required rate r is much larger than the typical values used in practice.

The amount of power delivered to the person in contact with the line can be written as

$$P = P_0 T_0 r \quad . \tag{11}$$

For line-of-sight coupling[6]

$$t_0 = \frac{\Delta R}{c} = \frac{\left[d^2 + (h + H)^2\right]^{1/2} - \left[d^2 + (h - H)^2\right]^{1/2}}{c} \quad , \quad t_\ell = \frac{\ell}{c} \quad , \tag{12}$$

where ΔR is the difference in path between the direct and reflected waves; h, H are the heights of the line and the simulator, respectively; and d is the horizontal distance between them. The surface waves are assumed negligible in comparison with the space waves.

Figure 3 shows plots of the required repetition rate of the simulator to deliver power P = 10 W ($1 \mathrm{mW/cm^2} A$, $A \approx 1 \mathrm{m^2}$, cross-sectional area of the person) to the person in contact with the line. The line is at height h (on a hill or on top of a tall building); H = 20 m, ℓ = 15 m, and $E = 25 \times 10^5/d$ V/m. In the concern of the general public (d > 1 km), there is no EMP hazard for practical repetition rates.

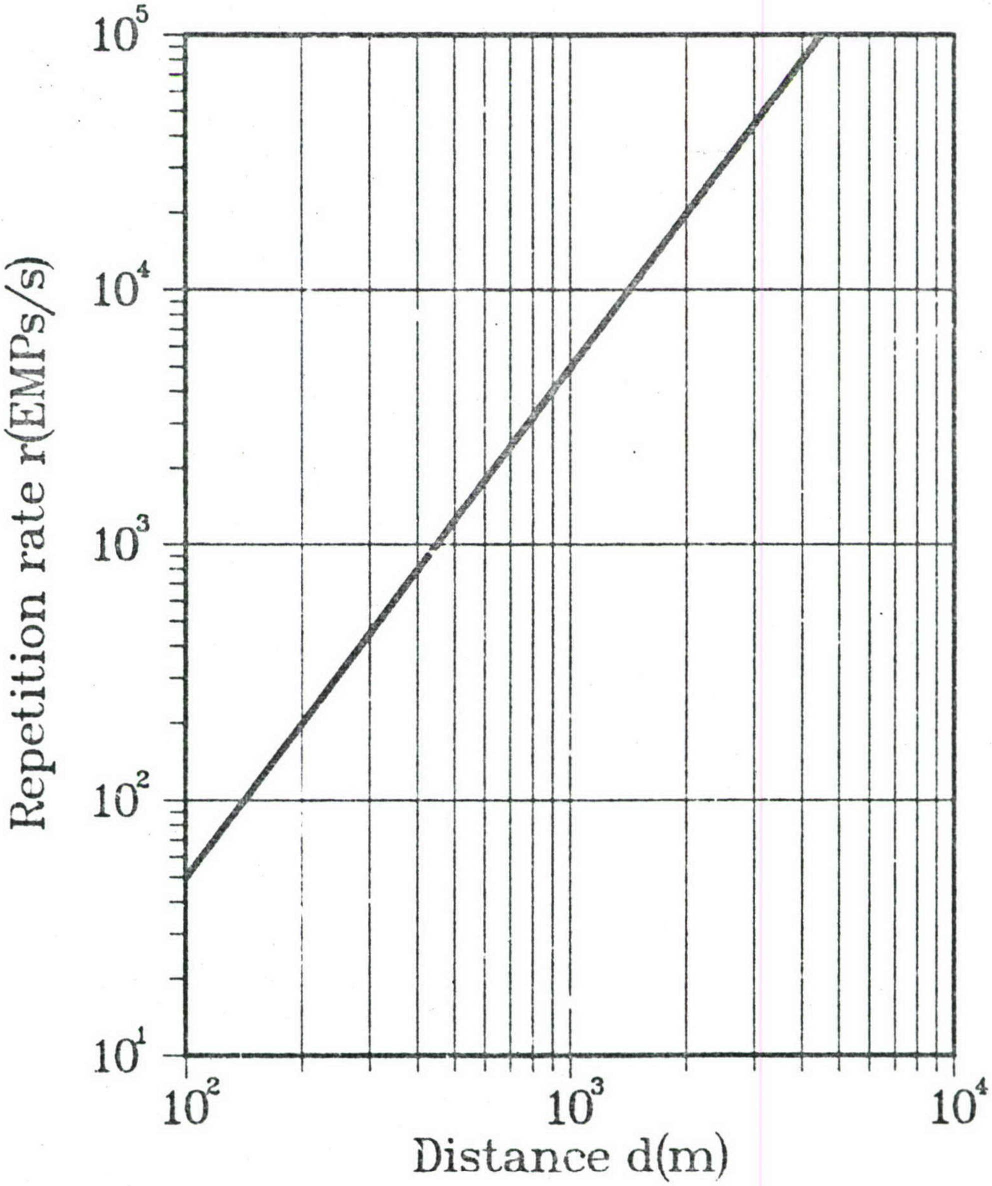

Fig. 2. Required repetition rate (r) for a simulator radiating far-field $E = 25 \times 10^5/d$ V/m to deliver 1 mW/cm^2 at a distance d

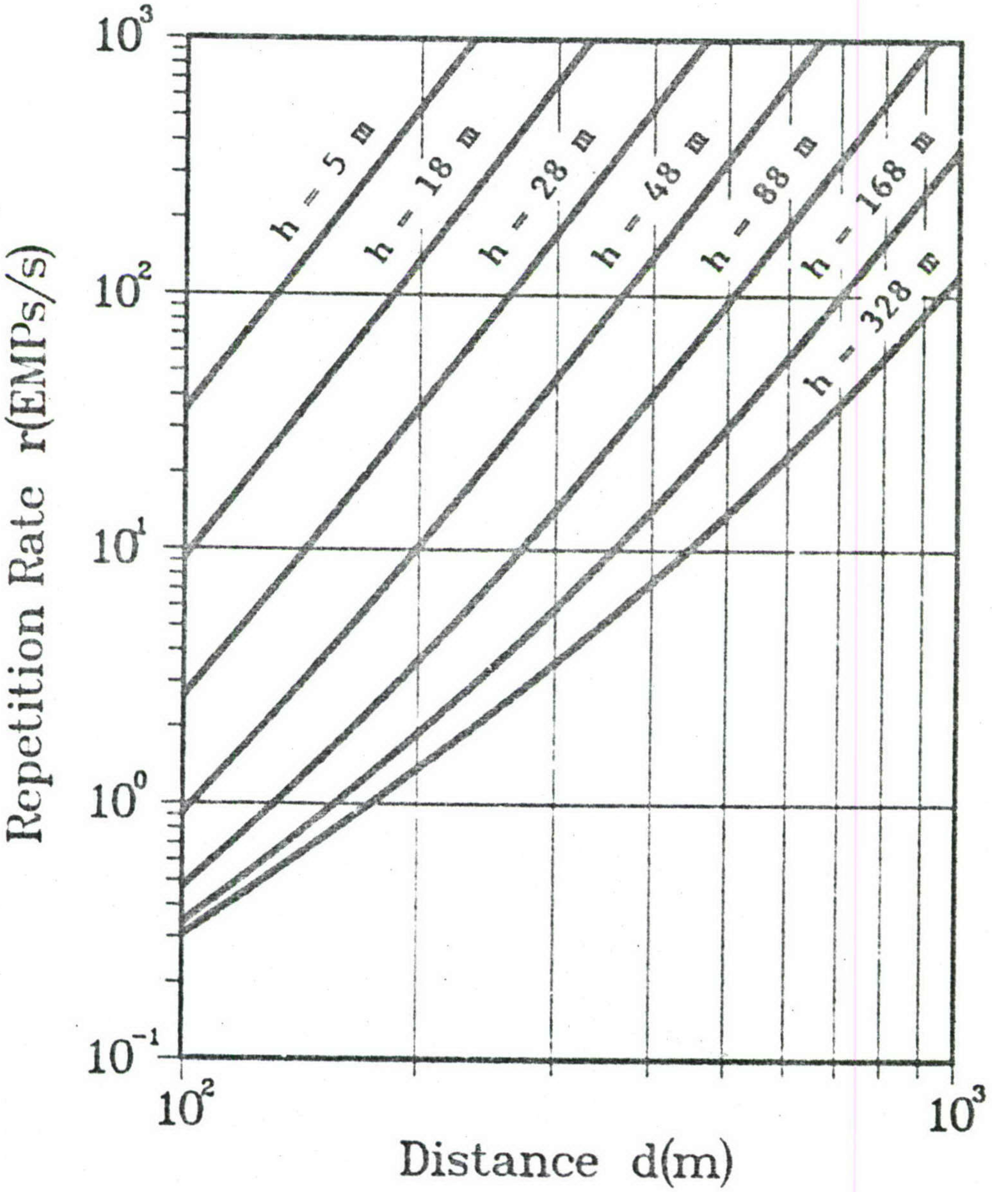

Fig. 3. Required repetition rate (r) for a simulator at height H = 20 radiating E = 25 x 10^5/d V/m to deliver P = 10 W to a person in contact with line of ℓ = 15 m at the top of a building of height h and at a distance d

Conclusion. The conclusion gained from this investigation demonstrates that any electromagnetic field hazards produced by EMP simulators are not harmful to the general public.

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APPENDIX C

BRIEF DESCRIPTION OF OCCUPATIONAL EPIDEMIOLOGY LITERATURE AND A POSSIBLE RISK OF CANCER

Abstracted from

"Electromagnetic Fields and Public Health"

T. E. Aldrich and C. E. Easterly

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Occupational and Community Based studies

Following the early Russian reports of subjective distress from electrical fields several clinical studies were performed on electrical substation workers, in Spain and Canada. No statistically significant health effects were observed and subjective reports of gastrointestinal symptoms and anxiety were associated with spark discharges and noise from the energized lines (1,2). A later study in Sweden using age, race and sex-matched comparison subjects, and larger numbers of workers found no difference on clinical testing, but decreased fertility in the exposed workers, specifically, fewer male children (3). Stopps and Janschevsky (4) found no clinical differences between exposed and nonexposed substation workers.

Two occupational, epidemiologic studies from Sweden have described health effects in relation to electromagnetic field exposure. They contain several differences from those reported thus far. First, a retrospective, questionnaire study was used with substation workers to consider reproductive effects. An increase of [all] birth defects was found for conceptions during the father's work on high-voltage systems. Pregnancies from time periods of other work activities were used for comparison purposes. The published data from this report may be used to calculate a risk estimate of 3.2 (6). The second Swedish study used a historical cohort design with workers in electrical occupations in 1960.

Follow-up of the study population through 1973 led to risk of 1.5 for both pharyngeal and lung cancers. This study used data from the Swedish Cancer Registry and a national occupational data base; despite this, the number of cancer cases was small (6).

The results of a large case-comparison mortality study of pediatric neuroblastomas in Texas were recently reported (7). Birth certificates of all children dying of neuroblastoma between 1964 and 1978 were reviewed; two comparison birth certificates were selected from the same year of birth. Paternal occupations were studied using a computerized software package for linking exposures to job titles. The comparability of cases and comparison of subjects were verified for sex, urban or rural, maternal and paternal age, duration of prenatal care, and rate of illegitimacy. Job titles classified as being associated with electromagnetic field exposures gave an odds ratio of 2:1; the odds ratio for fathers reported as electronics workers was 11.7 (small numbers were involved with this category). Not all of the jobs with electric or electrical in the title were exclusively linked to electromagnetic field exposure. Spitz and Johnson (7) raise the question about other possible exposures with these jobs that might explain an increase in disease risk, such as, for example, dusts, fumes and hydrocarbon exposures.

A case-comparison analysis of leukemia deaths among four cohorts of coal miners was made (8). Forty cases were identified among 6066 deaths in a total cohort of approximately 19,000 coal miners; age-to-death matched (4 to 1) comparison deaths were chosen from the same cohort. Exposure to electromagnetic fields was inferred on the basis of work

underground for more than 25 years. This questionable exposure surrogate, the different lengths of follow-up for the cohorts, and the small number of cases are some of the weaknesses associated with this exploratory study. The authors found an overall odds ratio for leukemia of 2.53 and acknowledge the potential role played by other occupational exposures. Cigarette smoking histories and the frequency of coal miner's pneumoconiosis were comparable between groups. The data for one study (presented in Table 2) are for all leukemias and subsets selected for comparison with those cell types reported by other investigators. Gilman et al. (8) found an odds ratio of 8.22 ($p < 0.05$ level, 95% confidence bounds of 1.12 and 60.42) for chronic lymphocytic leukemia at this site.

Proportional Mortality Studies

One aspect of the controversy surrounding electromagnetic fields derives from a series of studies conducted with population-based data representing many different geographical areas. These studies use an analytic calculation called the Proportional Mortality Ratio (PMR), a method whose limitations are known (9-11). The case and comparison data is taken from death certificates, as is the exposure information (occupational group). The basis of analysis is the proportion of deaths within certain groups (i.e., occupation titles) that are due to a certain cause. These investigations are intended for the purposes of generating hypotheses; yet, their convenience makes them useful for testing the consistency of an association across groups (12,13).

The first of these studies to link occupations with electromagnetic exposures came from Washington State. It cited PMRs in the range of 1.4 to 1.6 for adult leukemia (males, 20 years of age and older) (14). A similar study from California reported findings of the same sort using cancer incidence data. This report examined subgroups of leukemia cell types from the cases (white males) diagnosed from 1972 to 1979. The risk estimates from the "all-jobs" category were from 1.3 to 2.1. Acute, myelogenous leukemia was suggested as having the greatest association with electrical occupations (15).

A British study using leukemia incidence data for white males aged 15-74 years (1961-1979) reported risk estimates for all leukemia and acute myelogenous type around 1.2 (16). A study of leukemia deaths in England and Wales from 1970 to 1972 (males aged 15-74 years) gave PMR values for various electrical occupations between 1.2 and 2.3 for leukemia and myeloid subgroups (17). In a companion study ,the 1973 certificates for male leukemia deaths over 15 years of age were matched by age, sex and year-of-death to noncancer death certificates. Again, electrical occupations were found to be associated with the leukemia deaths with a statistically significant odd's ratio of 2.1 (17).

The National Institute for Occupational Safety and Health (NIOSH) (19) conducted an investigation of cancer mortality at an electronics manufacturing plant in Wisconsin. Deaths among approximately 99% of the company's employees were ascertained for the period from 1950 to 1980. This study reported a PMR for brain cancer (both sexes, all salary groups) of 1.95. A case-comparison analysis was performed with (4 to 1) matched

subjects from the same company. The analysis focused on specific job categories; however, because of the small number, only three groups could be analyzed (machine operators, maintenance workers, and office workers). For these groups, the respective odds ratios were 1.4, 3.0 and 3.0; the description in Table 2 is for the machine operators category (19). Brain cancer was studied in Maryland men (20 years and older) for the years 1969 to 1982. (20) A PRO of 2.78 as cited for occupations thought to have high electrical field exposure. Lin et al. (20) used a case-comparison design to further test this possible association and cited an odds ratio of 2.15 for brain cancer and electrical occupations.

Recently, Milham (21) reported on leukemia mortality among members of a group of amateur radio operators in Washington State and California. Male deaths from 1971 to 1983 were identified via the group's monthly newsletter; these were compared with mortality data for each state during the same time period. The PMR for all leukemia was 1.9, with PMRs for myeloid cell types ranging from 2.5 to 2.9 (21).

Pearce et al. (22) also report the findings for a case-comparison study performed in New Zealand. In this study, leukemia cases were matched to four other cancer cases in the National Cancer Registry. Occupations having presumed electric and magnetic field exposure were the criteria investigated. Electromagnetic field occupations gave an overall odds ratio of 1.7 with some subcategories indicating no increased risk and others having odds ratios from 3.9 to 8.1 (22).

A PMR study using 1963 to 1978 mortality data (white males 20 years of age and older) from the state of Wisconsin was reported recently (23).

Electrical occupations were analyzed to assess the risk of leukemia and acute leukemia; the PMRs based on all electrical occupations were 1.03 and 1.13, respectively. Most of the occupation-specific PMRs were less than 1.0, and the patterns observed by Milham (14) and Wright et al. (15) were not observed in the Wisconsin findings. Elevated PMRs were reported for both electrical engineers (see Table 2) and radio and telegraph operators (PMR = 2.35 and 3.0 for leukemia and acute leukemia, respectively) (23).

Table 2. Epidemiologic Studies of ELF Fields - Some Calculations

Lead Author	Ref. No.	End Point	Risk Level[a]	Confidence Limits[b]	Power for a Risk of 2.0[c]
Milham	14	Leukemia	PMR=1.37	(1.12-1.67)	>0.99
		Acute leukemia	PMR=1.63	(1.14-2.25)	>0.99
Wright	15	Leukemia	PIR=1.29	(0.85-1.88)	>0.99
		Acute leukemia	PIR=1.73	(0.93-2.93)	>0.91
		Myeloid leukemia	PIR=2.07	(1.02-3.75)	>0.85
McDowall	17	Leukemia	PMR=1.25	(0.65-2.19)	>0.88
		Myeloid leukemia	PMR=1.79	(0.66-3.88)	>0.65
		Acute myeloid leukemia	PMR=2.31	(0.61-6.00)	>0.49
		Myeloid leukemia	OR=2.1	(1.24-3.59)	>0.97
Coleman	16	Leukemia	PRR=1.17	(0.95-1.44)	>0.99
		Myeloid leukemia	PRR=1.23	(0.81-1.80)	>0.99
Vagero	6	Larynx	RR=1.46	(1.05-2.03)[d]	>0.99
		Lung	RR=1.52	(1.35-1.72)[d]	>0.99
Nordstrom	5	Birth defects	OR=3.24	(1.28-8.22)	>0.99
Swerdlow	18	Ocular cancer	PRR=2.40	(1.21-4.33)	>0.95
NIOSH	19	Brain cancer	PMR=1.95	(0.95-3.49)	>0.62
			OR=1.40	(0.38-5.50)	>0.16
Lin	20	Brain cancer	PMR=2.78	(1.65-4.39)	>0.99
		Brain cancer	OR=2.15	(1.07-4.32)	>0.99
Pearce	22	Leukemia	OR=1.70	(0.97-2.97)	>0.55
Milham	21	Leukemia	PMR=1.91	(1.22-2.84)	>0.90
		Myeloid leukemia	PMR=2.89	(1.61-4.55).	>0.63
Spitz	7	Neuroblastoma	OR=2.13	(1.05-4.35)	>0.78
Gilman	8	Leukemia	OR=4.16	(1.04,6.18)	>0.64
		Acute leukemia	OR=2.71	(0.82,9.90)	>0.30
		Myeloid leukemia	OR=3.75	(0.98,22.95)	>0.22
Calle	23	Leukemia	PMR=1.86	(0.99,3.18)	>0.59
		Acute leukemia	PMR=2.57	(1.11,5.06)	>0.31

[a]OR = Odds ratio; PMR = proportional mortality ratio; PIR = proportional incidence ratio; PRR = proportional registration ratio; RR = relative risk; SMR = standardized mortality ratio.

[b]As per Haenszel WD, Loveland B, Sirken MG: Lung cancer mortality as related to residence and smoking histories. 1. White males. J. Nat. Cancer Inst. 1962; 28: 1000-1001; and Schlesselman JJ: Case-control studies: design, conduct, analysis. Oxford University Press, New York: 1982.

[c]Assumes 1-tail test with alpha = 0.05; power = 1 beta as per Beaumont JJ, Breslow NE: Power considerations in epidemiologic studies of vinyl chloride workers. Am. J. Epidemiol. 1981; 114: 725-734; and Schlesselman, JJ: Case-Control Studies. Pub. Oxford Univ. Press, New York. Power is the ability of a study to find a certain level of risk if it truly exists in the study population. The number of study subjects is a principal concern with this probability.

[d]Published confidence intervals using a stratified chi-squared and Miettinen's form. Miettinen O: Estimability and estimation in case reference studies. Am. J. Epidemiol. 1976; 103: 226-235.

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